# SULFUR IN CALIFORNIA AND NEVADA

BY GEORGE C. BRANNER

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# SULFUR IN CALIFORNIA AND NEVADA[1]

by

George C. Branner[2]

## INTRODUCTION

This study was planned to present salient facts of the California and Nevada sulfur industries and to indicate existing opportunities for increased economic utilization of California and Nevada sulfur resources.

Numerous publications on sulfur have been issued by the Federal Bureau of Mines, including Information Circular 6329, Sulfur, by Robert H. Ridgway (1930); annual Minerals Yearbook chapters on Sulfur and Pyrites, by various authors; and a chapter on Sulfur by G. W. Josephson in Bureau of Mines Bulletin 556, Mineral Facts and Problems (1956). This literature, however, deals primarily with the national and international sulfur situation and does not attempt to analyze the possibilities for increased economic development of sulfur resources by individual States. The present study attempts to analyze these possibilities in California and Nevada and to (1) evaluate factors that have influenced production and consumption in California and Nevada and (2) indicate apparent trends in production, consumption, and prices in these States.

## SUMMARY

Sulfur as referred to in this study includes both elemental and combined sulfur. The sulfur may be chemically combined, as in iron sulfide, hydrogen sulfide, sulfur dioxide, or sulfuric acid.

The sources of sulfur in California and Nevada are:

1. Native sulfur (sulfur ore).

2. Pyrite.

3. Oil-refinery gases, from which hydrogen sulfide or elemental sulfur is recovered.

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4. Smelter gases, from which sulfur dioxide is recovered.

For the 52-year period, 1906-57, California and Nevada have produced abou 3,546,000 long tons of sulfur valued at $58,328,000. More than 99 percent of this sulfur, by quantity and value, has originated in California.

Although eight known deposits or groups of deposits of native sulfur in California and two in Nevada appear to have commercial possibilities, only one deposit has been operated on a substantial scale. This is now being worke as the Leviathan mine of The Anaconda Company, Alpine County, Calif. Ore from this mine is trucked to a plant near Yerington, Nev., for making sulfuric acid

Only one pyrite mine, the Hornet mine of The Mountain Copper Co. of California, Shasta County, Calif., has produced consistently.

Total production in California of oil-refinery elemental sulfur or "brimstone" and hydrogen sulfide, in terms of sulfur content, is now slightly greater than that of sulfur from native sulfur and pyrite. Production, in terms of sulfur content, from oil-refinery gases has grown from about 15,000 long tons in 1948 to about 149,000 long tons in 1957. Initial recovery from petroleum sources in 1937 was due primarily to efforts to reduce air pollution but as the technology of recovering hydrogen sulfide and elemental sulfur from refinery gases improved the practice has become of increasing economic importance in refinery operation. Today, recovery usually would be continued irrespective of the existence or nonexistence of air-pollution problems. At present no oil refineries are operating in Nevada.

Relatively little liquid sulfur dioxide and sulfuric acid are recovered from smelter gases in California, and none is recovered in Nevada. It does not appear likely that recovery from this source will increase substantially.

Data on reserves of native sulfur are meager, and substantial exploratory work remains to be done both in California and Nevada before a significant overall estimate can be made of reserves.

Pyrite reserves of the Hornet mine, in Shasta County, Calif., are believe to be sufficient to permit shipments at present levels for at least 10 years. A reserve of sulfide fines, principally pyrite, of approximately 13,200,000 short tons exists in Kennecott Copper Corp., Nevada Mines Division, mill-tailings dump at McGill, Nev. This reserve is not being exploited, because no economic means for its use has yet been devised.

Basically the possibility of expanding sulfur production in California and Nevada depends on the substitution of locally produced sulfur for importe sulfur. At present, net imports (all interstate) are estimated to be about 95,000 long tons annually of Gulf coast (and occasionally Wyoming) sulfur, or about one-third the total estimated consumption. Sulfur recovered from refinery hydrogen sulfide may, in a few years, supply 17,000 long tons of this amount. The balance (about 78,000 long tons) would have to come from increase cracking capacity of refineries, sulfur ore, or pyrite or be imported from other States. Whether or not this much ore or pyrite can be produced in

California depends upon: (1) Determining the economic reserves of known sulfur ore deposits and occurrences now regarded as potentially competitive, and (2) relating a sulfur-producing to a sulfur-consuming industry in such a way as to make the delivered price of local sulfur competitive. An example of the latter is the relation between sulfur-ore production at the Leviathan mine and its consumption near Yerington, Nev.

Developing a new source of pyrite does not appear encouraging, but economic means may be found to utilize the large reserve of pyrite in the tailings dump of the Kennecott Copper Corp., Nevada Mines Division, smelter at McGill, Nev.

## ACKNOWLEDGMENTS

The present study was begun in January 1956 by J. D. McLenegan. Before the study was completed, however, he resigned from the Federal Bureau of Mines.

Much use has been made of Bureau of Mines publications on sulfur, especially recent annual chapters on Sulfur and Pyrites from the Minerals Yearbook and the chapter on Sulfur from Bureau of Mines Bulletin 556, Mineral Facts and Problems. Edward J. Matson, of the Bureau, contributed most of the data given under the heading, Deposits, Occurrences, and Reserves, and additional information was gathered on field trips by other personnel of the Bureau and Federal Geological Survey. Miscellaneous data were obtained from the California Department of Natural Resources, Division of Mines, especially from Bulletin 176, (chapters by P. A. Lydon on Sulfur and C. W. Chesterman on Pyrites) and from the Nevada Bureau of Mines and Agricultural Extension Service of the University of Nevada.

D. D. Blue, of the Bureau, supplied data on sulfuric acid consumption in Nevada, and officials of the Bureau of Chemistry of the California Department of Agriculture cooperated. Several officials of sulfur producing or consuming industries also cooperated, including Don M. Patterson and Russell White, of the Stauffer Chemical Co.; I. Bergsteinsson, of Brea Chemicals, Inc.; Fred Lawrence and Paul Leonard, of Kennecott Copper Corp., Nevada Mines Division; Laurance Kett, of The Mountain Copper Co. of California; and officials of the Standard Oil Co. of California, Union Oil Co. of California, Hancock Chemical Co., American Smelting & Refining Co., Columbia-Geneva Division and Consolidated Western Division of United States Steel Corp., Bethlehem Pacific Coast Steel Corp., and Pacific States Steel Corp.

## HISTORY OF SULFUR PRODUCTION

### California

#### Native Sulfur

The first recorded production of native sulfur in California on a commercial scale was in 1865 by the Sulphur Bank mine in Clear Lake district, Lake County. This mine also yielded considerable quicksilver during its life. It was operated by the California Borax Co. in conjunction with its borax plant

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at nearby Borax Lake. During the 4 years, 1865-68, 840 long tons of refined sulfur valued at $53,000 was produced from an open-pit operation. Sulfur was extracted, using cast-iron retorts. The enterprise was abandoned as unprofitable in 1868.

In 1891 the Elgin mine, near Wilbur Springs in Colusa County, was operated, and some 30-percent sulfur ore was retorted. Owing to quicksilver contamination, the product was black sulfur and proved unmarketable. In 1918 another attempt was made to produce sulfur; two steam-heated retorts were installed, but the product could not be sold. A third attempt at development was made by Pacific Sulfur & Industrial Minerals Co. in 1929. Production was small and ceased in 1931.

In 1917 sulfur was discovered on the western slope of the Last Chance Range in Inyo County, about 5 miles west of the north end of Death Valley and east of Big Pine, and claims were located in the area. Small-scale production of sulfur ore was begun that year, but active development did not take place until 1929, when the Pacific Sulfur Co. undertook mining operations on the Crater claims. The company continued mining the claims through 1930. In 1931 and 1932 other operators worked the claims, and it is reported that 30,00 tons of 75- to 80-percent sulfur ore had been shipped to Los Angeles by June 1932. In 1934 the Western Sulfur Industries was reported to have shipped 4,50 tons of 96-percent ore; and in 1936 and 1937 Sulfur Diggers, Inc., installed retorts and was reported to have shipped 5,000 tons of 96-percent ore and some refined sulfur. Until 1958, other lessees have worked the deposits at times.

Other Inyo County claims, referred to as the Gulch group, are situated about 1-1/2 miles east of the Crater group. These claims have been less productive than the Crater group; they include the Gulch, Fraction, Black Sulfur, Southwest Sulfur, and Yellow Sulfur claims.

Total production from Inyo County deposits through 1957 has been estimate to be about 46,900 long tons of sulfur as ore.

In 1922 the California Sulphur Co. constructed a plant to treat low-grade sulfur ore from near-surface sedimentary deposits in the vicinity of the Sunset Oil field near Maricopa, Kern County, and 185 tons of sulfur was shipped in 1923 and 1924.

Two small occurrences of sulfur were worked in Imperial County between 1928 and 1932. One, the Swallow claim, is on the southwest slope of the Chocolate Mountains in the north-central part of the county; the other, the Full Moon property, is on Coyote Mountain 7 miles north of Coyote Wells.

The Canary Hill mine, at Chalk Mountain near Cache Creek, Lake County, was first worked before 1890 and was relocated in 1951. The Chemi Sales Corp. leased the property from 1952 to 1954.

The most recent, and by far the most important, native sulfur-mining operation in California has been that of the Leviathan mine of The Anaconda Compan in Alpine County. Although copper was produced from this mine in the early

1860's, only a little of the sulfur associated with the copper minerals was produced - in 1933 and 1934. Production figures for this operation are not available. The Anaconda Copper Mining Co., now The Anaconda Company, in planning its Yerington (Nev.) copper oxide leaching plant, recognized the possibilities of this nearby California deposit as a source of sulfur for making sulfuric acid and developed the deposit. Production was begun in 1953. From 1953 to 1957, inclusive, approximately 253,000 long tons of contained sulfur was shipped. This figure compares with the 29-year estimate of Inyo County production of about 46,900 long tons of sulfur as ore. In 1955 the production of sulfur ore in California was the largest ever recorded, and the Leviathan mine produced over 95 percent.

## Pyrite

The earliest output of pyrite in California was recorded by the Alma mine at Leona Heights in Berkeley Hills, Alameda County, in 1891. Pyrite occurs there in irregular, lenticular bodies in rhyolite. In 1906 the Stauffer Chemical Co. took over the mine and continued production until 1921. The Leona mine of the Leona Chemical Co. opened in 1895 and continued operations until 1934. Excessive unit mining costs were eventually responsible for the shutdown of these mines. Incomplete records indicate that 233,307 tons of pyrite, valued at $1,005,518, was produced during the life of the properties. The pyrite was used for making sulfuric acid.

Pyrite shipments were reported from a mine near Spenceville, Nevada County, by the Spence Mineral Co. in 1897, the ore being shipped to the San Francisco Bay area for sulfuric acid manufacture. This mine is reported to have opened originally in 1860 as a copper mine and to have produced about 150,000 tons of 5-percent copper ore before 1900.

Production of pyrite in Placer County was reported from the Dairy Farm Mining Co. mine near Sheridan in 1906 and 1915-16 and from the Valley View mine, 8 miles northeast of Lincoln, in 1912.

The Boss San Juan pyrite mine, 13 miles northeast of Nevada City, Nevada County, was worked for gold and copper from 1932 to 1938. Some development was done in 1952. Lenticular masses containing pyrite are known to be present and are estimated to contain more than 3,000,000 tons of pyrite averaging 40 percent sulfur.

## Oil-Refinery Byproducts

The first oil-refinery recovery of hydrogen sulfide was reported in 1937 by the Standard Oil Co. of California from its El Segundo refinery in Los Angeles County. The Shell Oil Co., with a refinery in Los Angeles County, first reported production of hydrogen sulfide in 1939. "Brimstone"or elemental sulfur production from hydrogen sulfide was first reported in 1949 by the Hancock Chemical Co., Los Angeles County. Production of oil-refinery byproduct sulfur and hydrogen sulfide has grown steadily since the end of 1948 and in 1957 was 149,093 long tons of contained sulfur, which was over half the total recorded production. In 1957, 11 oil refineries and 1 independent sulfur-recovery plant produced either elemental sulfur or hydrogen sulfide, from which sulfur or sulfur compounds were eventually made. Only about one-third of the hydrogen sulfide recovered was converted to sulfur by the producing refineries the remaining two-thirds was sold for processing by others.

### Smelter-Gas Byproducts

The American Smelting & Refining Co. smelter at Selby, Contra Costa County first reported output of sulfur dioxide as a byproduct in smelting sulfide ores in 1937. It was used to manufacture sulfuric acid. Production of liquid sulfur dioxide as a byproduct was first reported in 1953. The tonnage of these byproducts has been small.

To summarize, the history of sulfur production in California may be divided into three periods: (1) Pre-1906, (2) 1906-48, and (3) 1948-58.

In the pre-1906 period sulfur production came from ore only and was small and intermittent. The costs of mining, refining, and transporting the sulfur to market were such that the delivered-price competition of Sicilian and Japanese sulfur could not be met consistently, although attempts to compete were made by selective mining.

In 1906 the Hornet pyrite mine, Shasta County, began production, and until 1939 this mine was virtually the only source of sulfur in the State. Byproduct-sulfur production from oil refineries began in 1937, but through 1948 this source contributed only 15 to 25 percent of the total sulfur sold; most of the balance came from pyrite from the Hornet mine.

From 1948 to 1957, production of byproduct sulfur from oil refineries increased almost tenfold and in 1957 comprised 53.5 percent of the total sulfur output of the State. In 1953 the Leviathan mine, Alpine County, came into production as the largest producer of native sulfur in the history of the State. By 1957 it was producing 30.9 percent of the sulfur output of California, and exporting all of it to Nevada; the Hornet mine contributed most of the remainder of the mined sulfur ore or pyrite during the year.

## Nevada

### Native Sulfur

In 1868, about the time the first commercial sulfur was produced in California, the Rabbit Hole sulfur deposits, 29 miles northwest of Humboldt House and 3 miles east of Sulphur in Humboldt County, Nev., were discovered; however, these deposits were not worked until 1874 and then only on a small scale. In 1882 a plant with a daily capacity of 6 tons of sulfur was in operation. The Nevada Sulfur Co. of San Francisco assumed control of these deposits in 1900, and by 1903 two retorts were in operation. Each retort had a charge capacity of 2-1/2 tons of material and was operated by injecting superheated steam. The plant operated intermittently until 1923. In 1926 the Humboldt Sulphur Co. erected a mill on the property and for a short time produced 30 tons of sulfur daily from the Streeter mine. Since then, production has been intermittent. The Western Sulphur Corp. is at present operating the mines and plant. The sulfur has been used primarily as a soil aid.

As early as 1868 a deposit of sulfur was known to exist in the Alum district of Esmeralda County, Nev., 10 miles north of Silver Peak; however, little development was done on the property until 1921, when Western Chemicals Ore, of Tonopah, constructed an alum-sulfur treatment plant designed to produce, in addition to alum, 10 tons daily of 85-percent sulfur concentrate. The plant was operated intermittently until 1923. The property was known as the Alum mine.

A sulfur mine 1-1/2 miles northwest of Cuprite, Esmeralda County, Nev., known as the Deep Gulch mine, was developed before 1909, and from 1915 to 1923 ore was shipped to Hawaii as a soil aid.

The Steamboat Springs sulfur deposit in Washoe County, Nev., was discovered in 1875. Cinnabar was associated with sulfur in this area, and the Nevada Quicksilver Co. erected a quicksilver furnace at the deposit in 1877. Some sulfur was extracted as a byproduct.

### Pyrite, Oil-Refinery Byproducts, and Smelter-Gas Byproducts

No commercial pyrite has ever been recovered in Nevada, and no oil refineries are located in Nevada at present. There is no record of production of smelter-gas byproduct sulfur or sulfur compounds in Nevada.

## PRODUCTION, SHIPMENTS, AND VALUE

Sulfur or sulfur compounds are obtained from a wide variety of sources: Native sulfur deposits, pyrites deposits, sulfide-ore concentration plants and smelters, oil refineries, sour natural gas, coal-burning plants, and anhydrite deposits. The bulk (over 80 percent) of the domestic production comes from native sulfur deposits in Texas and Louisiana that can be mined by the low-cost Frasch process. Table 1 shows details of national production data. The delivered price of sulfur shipped from Frasch mines is the principal factor determining the competitive positions of California and Nevada sulfur. A comparison of tables 1 and 2 indicates that sulfur output in California and Nevada approximated 4 percent of the national total in 1957.

Sulfur in California and Nevada is derived from four sources, as follows:

| Source | | First product | Sulfur product |
|---|---|---|---|
| Mines: | Sulfur ore | Native sulfur ore | Elemental sulfur and sulfuric acid. |
| | Pyrite | Iron pyrite | Sulfuric acid. |
| Oil refineries | | Hydrogen sulfide in solution in ethanolamine. | Hydrogen sulfide and elemental sulfur. |
| Sulfide ore smelter | | Sulfur dioxide | Liquid sulfur dioxide and sulfuric acid. |

Federal Bureau of Mines statistics on the production, shipments, and value of California and Nevada sulfur are available for the periods 1906-25 and 1937-57 - a total of 41 years. Figures for the period 1926-36 were obtained from the California Division of Mines. Table 2 gives a breakdown of these figures, combined to conceal individual company operations. Figure 1 shows production data graphically.

TABLE 1. - Production of sulfur and sulfur-containing raw materials by producers in the United States, 1948-52 (average) and 1953-57, in long tons[1]

| | 1948-52 (average) | | 1953 | | 1954 | |
|---|---|---|---|---|---|---|
| | Gross weight | Sulfur content | Gross weight | Sulfur content | Gross weight | Sulfur content |
| Native sulfur or sulfur ore: | | | | | | |
| From Frasch-process mines.............. | 5,075,560 | 5,075,561 | 5,155,342 | 5,155,342 | 5,514,640 | 5,514,640 |
| From other mines[2]... | 4,664 | 1,455 | 151,819 | 38,257 | 214,157 | 64,333 |
| Total native sulfur | - | 5,077,016 | - | 5,193,599 | - | 5,578,973 |
| Recovered elemental sulfur: | | | | | | |
| Brimstone............ | 133,663 | 133,248 | 342,297 | 340,827 | 361,107 | 359,135 |
| Paste................. | 5,442 | 2,519 | 1,723 | 833 | 284 | 136 |
| Total recovered elemental sulfur.. | - | 135,767 | - | 341,660 | - | 359,271 |
| Pyrites (including coal brasses)............... | 952,039 | 402,110 | 922,647 | 379,545 | 908,715 | 405,310 |
| Byproduct sulfuric acid (basis 100 percent) produced at Cu, Zn, and Pb plants.......... | 651,390 | 212,804 | 775,069 | 253,000 | 791,049 | 258,600 |
| Other byproduct sulfur compounds[3]............ | 53,373 | 46,363 | 92,787 | 80,167 | 85,255 | 73,046 |
| Total equivalent sulfur............ | - | 5,874,060 | - | 6,247,971 | - | 6,675,200 |

| | 1955 | | 1956 | | 1957 | |
|---|---|---|---|---|---|---|
| | Gross weight | Sulfur content | Gross weight | Sulfur content | Gross weight | Sulfur content |
| Native sulfur or sulfur ore: | | | | | | |
| From Frasch-process mines............... | 5,738,978 | 5,738,978 | 6,423,883 | 6,423,883 | 5,491,212 | 5,491,212 |
| From other mines[2]... | 199,899 | 60,902 | 212,476 | 60,402 | 276,868 | 87,313 |
| Total native sulfur | - | 5,799,880 | - | 6,484,285 | - | 5,578,525 |
| Recovered elemental sulfur: | | | | | | |
| Brimstone............ | 400,754 | 398,601 | 466,848 | 464,629 | 511,936 | 510,307 |
| Paste................. | 380 | 179 | 287 | 129 | 452 | 204 |
| Total recovered elemental sulfur.. | - | 398,780 | - | 464,758 | - | 510,511 |
| Pyrites (including coal brasses)............... | 1,006,943 | 409,826 | 1,069,904 | 431,687 | 1,067,396 | 436,012 |
| Byproduct sulfuric acid (basis 100 percent) produced at Cu, Zn, and Pb plants.......... | 992,903 | 324,580 | 1,064,406 | 347,954 | 1,194,230 | 390,394 |
| Other byproduct sulfur compounds[3]............ | 106,129 | 93,712 | 102,300 | 89,428 | 102,157 | 88,446 |
| Total equivalent sulfur........... | - | 7,026,778 | - | 7,818,112 | - | 7,003,888 |

[1] From Bureau of Mines, Minerals Yearbook, 1957.

[2] Sulfur content estimated for 1948-52.

[3] Hydrogen sulfide and liquid sulfur dioxide. In addition, a quantity of acid sludge is converted to $H_2SO_4$, but is excluded from the above figures.

TABLE 2. - California and Nevada sulfur production, shipments, and value, 1906-57

(Production and shipment figures are in long tons of sulfur, elemental or contained)

| | California | | | | | |
|---|---|---|---|---|---|---|
| | Native sulfur and pyrite | | | Refinery and smelter byproduct sulfur | | |
| | Production | Shipments | Value | Production | Shipments | Value |
| 1906-38........... | 1,292,586 | 1,308,661 | $11,510,564 | 5,177 | 5,177 | $414,160 |
| 1939.............. | 29,436 | 29,164 | 481,967 | 16,469 | 15,705 | 462,358 |
| 1940.............. | 35,346 | 37,398 | 380,203 | 17,633 | 15,293 | 350,514 |
| 1941.............. | 41,621 | 43,944 | 467,047 | 18,598 | 19,307 | 476,810 |
| 1942.............. | 54,125 | 57,020 | 460,000 | 19,685 | 17,143 | 424,981 |
| 1943.............. | 43,975 | 49,594 | 526,966 | 17,834 | 18,979 | 369,714 |
| 1944.............. | 61,682 | 95,523 | 560,585 | 20,645 | 23,812 | 655,841 |
| 1945.............. | 29,510 | 44,087 | 266,239 | 17,058 | 20,277 | 571,546 |
| 1946.............. | 43,287 | 64,736 | 436,940 | 15,277 | 13,103 | 365,075 |
| 1947.............. | 62,733 | 88,783 | 645,950 | 18,042 | 10,987 | 437,375 |
| 1948.............. | 42,520 | 61,270 | 475,450 | 18,837 | 17,428 | 567,613 |
| 1949.............. | 73,511 | 74,461 | 534,444 | 36,143 | 35,790 | 1,209,139 |
| 1950.............. | 33,646 | 56,398 | 573,252 | 46,218 | 42,041 | 1,232,551 |
| 1951.............. | 71,842 | 93,783 | 953,581 | 64,519 | 44,502 | 1,582,095 |
| 1952.............. | 67,071 | 90,272 | 896,909 | 74,673 | 50,488 | 1,728,664 |
| 1953.............. | 70,894 | 79,298 | 1,455,120 | 95,180 | 75,622 | 2,603,379 |
| 1954.............. | 116,768 | 107,102 | 2,415,269 | 92,583 | 70,437 | 2,641,229 |
| 1955.............. | 118,925 | 107,139 | 2,511,264 | 127,312 | 103,533 | 3,551,543 |
| 1956.............. | 101,230 | 106,560 | 2,467,027 | 149,521 | 120,541 | 3,838,128 |
| 1957.............. | 127,081 | 89,363 | 2,258,342 | 152,357 | 152,072 | 4,220,473 |
| Total 1939-57 | 1,225,203 | 1,375,895 | $18,766,555 | 1,018,584 | 867,060 | $27,289,028 |
| Total 1906-57 | 2,517,789 | 2,684,556 | $30,227,119 | 1,023,761 | 872,237 | $27,703,188 |

| | California | | | Nevada | | |
|---|---|---|---|---|---|---|
| | Total | | | | | |
| | Production | Shipments | Value | Production | Shipments | Value |
| 1906-38........... | 1,297,763 | 1,313,838 | $11,924,724 | 2,426 | 2,426 | $271,963 |
| 1939.............. | 45,905 | 44,869 | 944,325 | 2,309 | 2,405 | 75,929 |
| 1940.............. | 52,979 | 52,691 | 730,717 | | | |
| 1941.............. | 60,219 | 63,251 | 943,857 | | | |
| 1942.............. | 73,810 | 74,163 | 884,981 | | | |
| 1943.............. | 61,809 | 68,573 | 896,680 | | | |
| 1944.............. | 82,327 | 119,335 | 1,216,426 | | | |
| 1945.............. | 46,568 | 64,364 | 837,785 | | | |
| 1946.............. | 58,564 | 77,839 | 802,015 | | | |
| 1947.............. | 80,775 | 99,770 | 1,083,325 | | | |
| 1948.............. | 61,357 | 78,698 | 1,043,063 | | | |
| 1949.............. | 109,654 | 110,251 | 1,743,583 | | | |
| 1950.............. | 79,864 | 98,439 | 1,805,803 | | | |
| 1951.............. | 136,361 | 138,285 | 2,535,676 | | | |
| 1952.............. | 141,744 | 140,760 | 2,625,573 | | | |
| 1953.............. | 166,074 | 154,920 | 4,058,499 | | | |
| 1954.............. | 209,351 | 177,539 | 5,056,498 | | | |
| 1955.............. | 246,237 | 210,672 | 6,062,807 | | | |
| 1956.............. | 250,751 | 227,101 | 6,305,155 | | | |
| 1957.............. | 279,438 | 241,435 | 6,478,815 | | | |
| Total 1939-57 | 2,243,787 | 2,242,955 | $46,055,583 | 2,309 | 2,405 | 75,929 |
| Total 1906-57 | 3,541,550 | 3,556,793 | $57,980,307 | 4,735 | 4,831 | $347,892 |

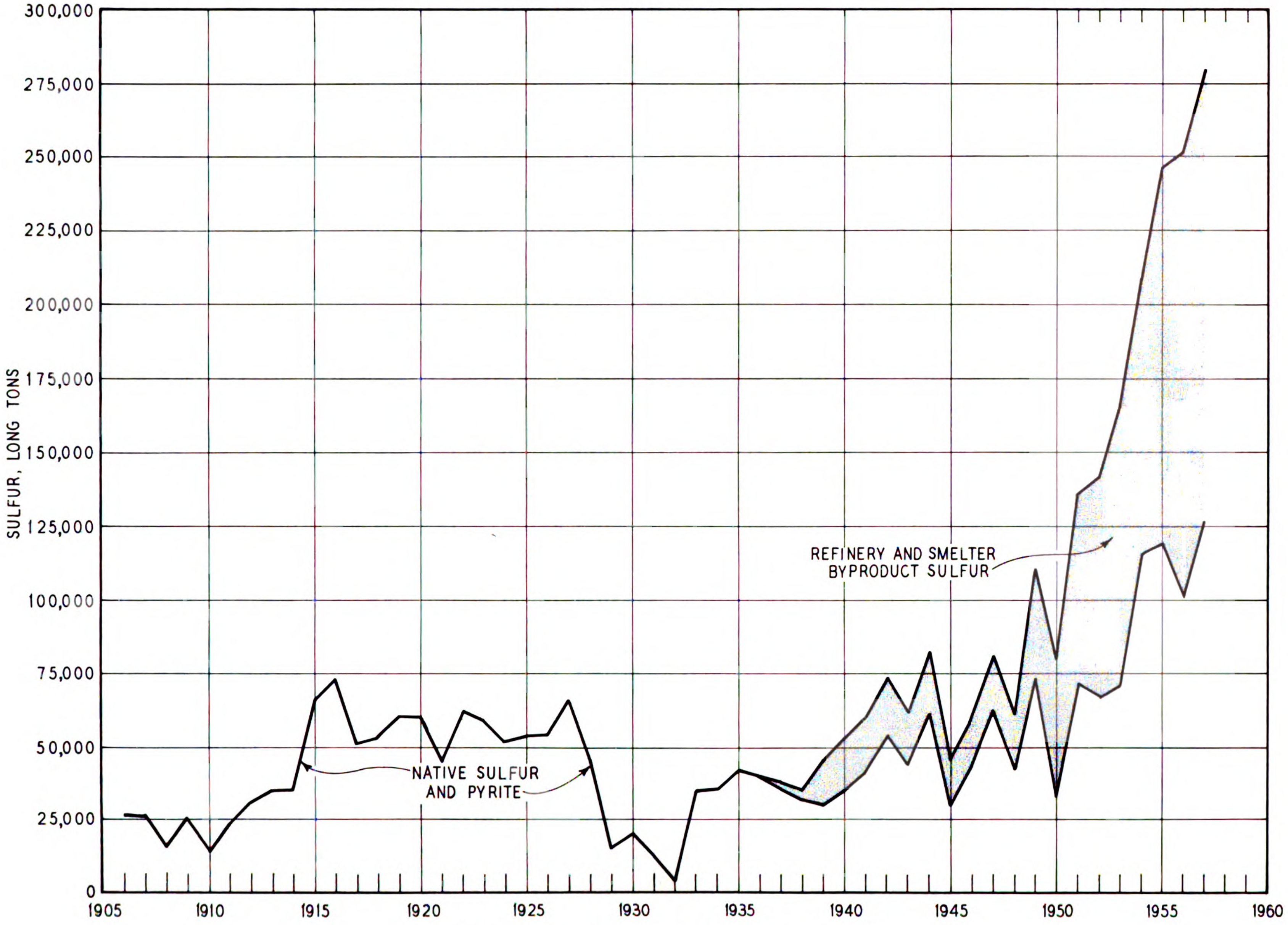

FIGURE 1. - Production of Sulfur in California.

Original from THE OHIO STATE UNIVERSITY

Following is a summary of the output of sulfur in California and Nevada, 1906-57. Production and shipments are in thousand long tons of sulfur, elemental or contained; values are in million dollars.

| Item | California | | | | | Nevada | | California and Nevada | |
|---|---|---|---|---|---|---|---|---|---|
| | Native sulfur and pyrite | | Refinery and smelter byproducts[1] | | Total | Ore | | | |
| Production........ | 2,518 | 71.1% | 1,024 | 28.9% | 3,542 | 5 | .1% | 3,547 | 100% |
| Shipments......... | 2,685 | 75.5% | 872 | 24.6% | 3,557 | 5 | .1% | 3,562 | 100% |
| Value............. | 30.3 | 52.2% | 27.7 | 47.8% | 58.0 | .3 | .6% | 58.3 | 100% |

[1] Recovered sulfur, hydrogen sulfide, and sulfur dioxide.

For the period 1906-57 the ratio of the value of California native sulfur and pyrite sulfur to refinery and smelter byproduct sulfur was 52.2 to 47.8. Since 1949, however, this relationship has changed radically owing to the increase in refinery sulfur production; the 1957 ratio was 34.8 : 65.2. The value of native sulfur production in California, which was 15.5 percent of the value of all sulfur produced in the period 1906-57, increased to 31.0 percent in 1957 owing to production from the Leviathan mine in Alpine County.

## Native Sulfur

### California

Inyo County was the principal producing county before 1953. A little native sulfur was also produced in Lake, Colusa, and Kern Counties. Published[3] estimates of production for these counties of 100-percent sulfur ore for the period 1865-1954 are: Inyo, 44,863 long tons; Lake, 798 long tons; Colusa, 230 long tons; and Kern 154 long tons. In 1953 the Leviathan mine began production, and 253,283 long tons of contained sulfur was shipped from this mine from 1953 through 1957, all of which was trucked to the vicinity of Yerington, Nev.

### Nevada

Sulfur has been produced only as ore in Nevada. Humboldt and Esmeralda were the only counties reporting specific tonnages, of which over 90 percent was produced by the Streeter mine in Humboldt County. A little sulfur is known to have been recovered as a byproduct of mercury mining in Washoe County. The 52-year production reported for Nevada was 4,735 tons of sulfur valued at $347,892.

## Pyrite

### California

The Hornet mine of the Mountain Copper Co. of California, Shasta County, has been the sole large and consistent producer of pyrite in California and

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[3] Lydon, Philip A., Sulfur and Sulfuric Acid: California Div. Mines Bull. 176, 1957, p. 618.

Nevada. The Bureau of Mines has estimated production from 1906 to 1957 at 4,100,000 tons of ore valued at $20,700,000. Incomplete figures for the Alma and Leona mines in Alameda County indicate a production of 233,307 tons of ore valued at $1,005,518 from 1901 to 1934. Minor amounts were produced intermittently in Placer and Mariposa Counties.

### Nevada

Commercial pyrite production, as such, has not been reported from Nevada; however, pyrites are commonly associated with other sulfide minerals that are or have been produced commercially.

## Refinery and Smelter Byproduct Sulfur

### California

When located near acid plants, refineries may supply hydrogen sulfide to these plants for direct conversion. The Standard Oil Co. of California, at Richmond, supplies the General Chemical Co. at Richmond; Tidewater Associated Oil Co., at Avon, supplies the Monsanto Chemical Co. at Avon; and Shell Oil Co at Dominguez, supplies Stauffer Chemical Co. at Dominguez. When no acid plant is near the refinery, the recovered hydrogen sulfide may be converted to elemental sulfur or burned. Union Oil Co. of California converts to liquid elemental sulfur at its refineries in Wilmington, Santa Maria, and Oleum, as does Wilshire Oil Co. with a refinery at Norwalk. Hancock Chemical Co., at Watson, converts hydrogen sulfide to liquid sulfur, purchasing hydrogen sulfide from General Petroleum Co., Richfield Oil Co., and The Texas Co. The liquid sulfur moves by insulated tank truck to acid plants. Minor quantities are converted to carbon disulfide and lime sulfur. Shell Oil Co., at Martinez, burns the separated hydrogen sulfide.

The following table shows the production and value of California refinery and smelter sulfur, elemental or contained.

| County | Number of oil refineries, recovery plants, and smelters reporting | Overall production period | Total sulfur production, thousand long tons | Value, million dollars |
|---|---|---|---|---|
| Contra Costa.......... | 4 | 1937-57 | 276 | $10.8 |
| Los Angeles and San Luis Obispo.......... | 9 | 1939-57 | 748 | $16.8 |
| Total........... | 13 | 1937-57 | 1,024 | $27.6 |

The American Smelting & Refining Co., Selby, Contra Costa County, is the only smelter in California or Nevada recovering sulfur compounds from stack gases. Sulfur dioxide has been converted to sulfuric acid since 1937 and to liquid sulfur dioxide since 1951.

## TABLE 3. - Producers, California and Nevada, 1952-57

### Sulfur ore

| CALIFORNIA | Mine | Nearest town |
|---|---|---|
| Alpine County: The Anaconda Company | Leviathan | Markleeville. |
| Inyo County: | | |
| D & B Sulfur Co | Gulch | Oasis. |
| Roy E. Kitching (Inyo Soil Sulfur Co.) | Crater group | Do. |
| Gertrude L. Ott | Fraction No. 1 | Do. |
| **NEVADA** | | |
| Humboldt County: | | |
| Black Rock Desert Mineral Co | Streeter | Sulfur. |
| Western Sulphur Corp | Crofoot and others | Do. |
| Sulfur Products, Inc | do. | |

### Pyrite

| CALIFORNIA | Mine | Nearest town |
|---|---|---|
| Shasta County: Mountain Copper Co. of California | Hornet | Matheson. |
| **NEVADA** | | |
| None. | | |

### Refinery byproduct sulfur

| CALIFORNIA<br>Hydrogen sulfide | Location | Extraction method |
|---|---|---|
| Contra Costa County: | | |
| Standard Oil Co. of California | Richmond | Girbotol. |
| Tidewater Associated Oil Co | Avon | Do. |
| Los Angeles County: | | |
| General Petroleum Corp.[1] | Torrance | Amine type. |
| Richfield Oil Corp.[1] | Watson | Girbotol (Richfield modification). |
| Shell Oil Co | Wilmington | Shell phosphate. |
| Standard Oil Co. of California | El Segundo | Girbotol. |
| The Texas Co.[1] | Wilmington | Amine type. |
| Hydrogen sulfide converted to elemental sulfur or brimstone | | |
| Contra Costa County: Union Oil of California | Oleum | Amine type and modified Claus. |
| Los Angeles County: | | |
| Hancock Chemical Co.[2] | Watson | Modified Claus. |
| Union Oil Co. of California | Wilmington | Amine type and modified Claus. |
| Wilshire Oil Co., Inc | Norwalk | Do. |

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See footnotes at end of table.

TABLE 3. - Producers, California and Nevada, 1952-57 (Con.)

| | Location | Extraction method |
|---|---|---|
| San Luis Obispo County: Union Oil Co. of California | Santa Maria | Amine type and modified Claus. |
| NEVADA | | |
| None | | |
| Smelter-Gas Byproduct Sulfur | | |
| CALIFORNIA | | |
| Sulfur dioxide and sulfuric acid | | |
| Contra Costa County: American Smelting & Refining Co | Selby | A. S. & R. |
| NEVADA | | |
| None. | | |

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1/ Hydrogen sulfide production is sold to Hancock Chemical Co., Watson, Los Angeles County.

2/ Purchases hydrogen sulfide from General Petroleum Corp., Richfield Oil Corp., and The Texas Co.

## CONSUMPTION

Sulfur is of economic importance chiefly because it can be used to manufacture sulfuric acid. This acid is by far the most important industrial acid in terms of volume consumed and has many commercial applications, of which the principal ones are manufacturing fertilizers and chemicals and refining petroleum. Large tonnages also are used in making paints and pigments, in iron and steel pickling, and in making rayon and cellulose film.

In addition to the acid uses of sulfur, substantial quantities also are consumed in nonacid uses, such as in making carbon disulfide, pulp and paper, fungicides, insecticides, and rubber and for soil treatment. Nationally, nonacid consumption approximates 20 percent of the total, which is approximately the proportion consumed in the California-Nevada area.

Comprehensive consumption statistics are compiled only intermittently by Government agencies. These statistics are supplemented occasionally by estimates published by trade magazines. Available national data are included in the annual Sulfur and Pyrites chapters of the Minerals Yearbook of the Federal Bureau of Mines.

### California

### Consumption Estimate

Figures for sulfur consumption in California in 1957 have been compiled from estimates based upon a study of data furnished by California State agencies, manufacturers, and large users. No complete canvass of consumers has been made, but it is believed that the figures represent a fairly realistic picture of the 1957 use pattern. A description of how the figures were compiled is given in the following pages. All figures represent sulfur content of sulfur materials.

TABLE 4. - Consumption of elemental or contained sulfur, California, 1957

| | | Long tons | Percent of total |
|---|---|---|---|
| 1. As 100-percent sulfuric acid | For petroleum refining....... | [1]70,000 | 24.3 |
| | For pickling steel........... | 8,000 | 2.8 |
| | For manufacturing fertilizers | 95,000 | 33.0 |
| | For other uses (chemicals, paints, pigments, rayon, films, and miscellaneous)... | 58,000 | 20.1 |
| Subtotal.... | | 231,000 | 80.2 |
| 2. For direct agricultural use: Soil sulfur, insecticides, and fungicides. | | 34,000 | 11.8 |
| 3. Other nonacid uses: Rubber, carbon disulfide, etc. | | 23,000 | 8.0 |
| Total.... | | 288,000 | 100.0 |

---

[1] Excludes recycled acid.

Another significant breakdown of the above figures is:

| | Long tons | Percent of total |
|---|---|---|
| 1. Sulfur for agricultural use: | | |
| For fertilizer manufacture.................. | 95,000 | 33.0 |
| For direct agricultural use.................. | 34,000 | 11.8 |
| Subtotal.............................. | 129,000 | 44.8 |
| 2. For use other than agricultural.............. | 159,000 | 55.2 |
| Total................................ | 288,000 | 100.0 |

Two other conclusions as to California consumption of sulfur are:

1. Sulfuric acid manufacture absorbs virtually the entire output of byproduct sulfur in the State, all of the pyrite produced in the State, and about 40 percent of the imported (interstate) sulfur.

2. Direct applications of agricultural sulfur and nonacid uses other than agricultural absorb approximately the remaining 60 percent of imported (interstate) sulfur.

These conclusions are reached as follows. The total acid requirement, in terms of sulfur (231,000 tons), is about 38,000 tons greater than the sum of the shipments of byproduct sulfur and the sulfur content of the pyrite shipments. Sulfur provided by these two sources is known to be used almost entirely for acid manufacture. As the additional tonnage required for acid manufacture can come only from rail imports (interstate), estimated at 95,000 tons, it follows that about 40 percent of these rail shipments is absorbed in acid manufacture; the remaining 60 percent (57,000 tons) is used for agricultural and nonacid uses other than agricultural.

TABLE 5. - Sulfur balance, California, 1957

| | Income (long tons) | Percent |
|---|---|---|
| Rail imports (interstate)........................ | 1/95,000 | 28.3 |
| Mined sulfur and pyrite shipments............... | 89,000 | 26.5 |
| Oil-refinery and smelter-gas sulfur shipments..... | 152,000 | 45.2 |
| Total.................................... | 336,000 | 100.0 |
| | **Outgo (long tons)** | **Percent** |
| Consumption........................................ | 288,000 | 85.7 |
| Exports: Rail, water, and truck (interstate)..... | 48,000 | 14.3 |
| Total.................................... | 336,000 | 100.0 |

1/ Average figure. Carload Waybill Statistics, Interstate Commerce Commission (See data on Rail Imports in section on Trends.)

### Explanation of Consumption Estimate

#### Sulfuric Acid Manufacture

The estimate is based upon sales data of sulfuric acid manufactured in California in 1957. The assumption is made that all acid produced by the nine active plants in California is consumed in California, as only a negligible amount of (battery) acid is exported to foreign countries. Acid production is estimated on a 100-percent basis, and the acid is assumed to contain 32.7 percent sulfur.

#### Petroleum Refining

The estimate is based upon sales data of the 36 oil refineries reported as operating in California in 1957.

#### Pickling Steel

The estimate is based upon the sulfur content of the aggregate 1956 consumption of 100-percent acid as reported by Columbia-Geneva Steel Division and Consolidated Western Division, United States Steel Corp., the former with plants at Pittsburg, Contra Costa County, and Torrance, Los Angeles County, and the latter with a plant at South San Francisco, San Mateo County; Bethlehem Pacific Coast Steel Corp., with plants at South San Francisco, San Mateo County and Los Angeles, Los Angeles County; Kaiser Steel Corp., with a plant at Fontana, San Bernardino County; and Pacific States Steel Corp., with a plant at Niles, Alameda County. Steel production in California in 1957 was only 1.1 percent greater than in 1956; hence the 1956 estimate is assumed to approximate the 1957 figure.

## Fertilizer Manufacture

The estimate was made from the following figures for California fertilizer sales in 1957, supplied by the Chemistry Department of the California Department of Agriculture.

TABLE 6. - Sulfur content of fertilizers consumed in California, 1957

| | Fertilizer, short tons | Calculated sulfur content, long tons |
|---|---|---|
| Normal superphosphate | 60,216 | 6,453 |
| Treble superphosphate | 17,407 | 3,497 |
| Ammonium sulfate | 163,230 | 39,026 |
| Potassium sulfate | 5,890 | 968 |
| Liquid phosphoric acid | 8,964 | 2,810 |
| Ammonium phosphate-sulfate | 56,347 | 7,698 |
| Ammonium phosphate: $13(N)+39(P_2O_5)+0(K_2O)$ | 4,297 | 288 |
| Ammonium phosphate: $11(N)+48(P_2O_5)+0(K_2O)$ | 10,202 | 319 |
| Ammoniated superphosphate | 3,283 | 410 |
| Mixed dry fertilizer | 220,283 | 33,048 |
| Total | | 94,517 |

## Other Sulfuric Acid Use

The estimate is based upon the difference between the sulfur used for sulfuric acid manufacture (231,000 long tons) and sulfur contained in the sulfuric acid used for petroleum refining, pickling steel, and making fertilizers.

## Direct Agricultural Use

The estimate is based upon the sum of the figure for soil sulfur sales in California in 1957 and the estimate of the sulfur used for insecticides and fungicides in 1957, as supplied by the Division of Plant Industry, California Department of Agriculture.

| | Calculated sulfur content, long tons |
|---|---|
| Soil-sulfur sales | 10,584 |
| Dusting | 22,968 |
| Total | 33,552 |

A sulfur-bearing mineral product not included in these calculations is agricultural gypsum. The California Department of Agriculture reported that 620,083 long tons of gypsum and gypsite were sold for agricultural use in California in 1957.

## Other Nonacid Use

The quantity of sulfur consumed for other nonacid uses is estimated at 23,000 long tons as follows: (1) Shipments (241,000), plus imports (95,000), less 48,000 (exports) equals 288,000 (apparent consumption); (2) 231,000 (acid use) plus 34,000 (direct agricultural use) equals 265,000. As apparent consumption is 23,000 tons larger than the sum of the tonnage used for acid and direct agricultural use, this difference is assumed to represent the other nonacid uses.

## Nevada

### Consumption Estimate and Sulfur Balance

TABLE 7. - Consumption and sulfur balance, Nevada, 1957[1]

| | Sulfur content, long tons |
|---|---|
| Fertilizers | 1,600 |
| As 100-percent sulfuric acid | 48,700 |
| Total | 50,300 |
| **Sulfur Balance** | |
| Income: | |
| Mined sulfur | 900 |
| Imports (interstate) | 50,300 |
| Total | 51,200 |
| Outgo: | |
| Consumption | 50,300 |
| Exports (interstate) | 900 |
| Total | 51,200 |

---

[1] Sources of consumption and sulfur-balance figures: Fertilizer tonnage based on 1957 estimate of Agricultural Extension Service, University of Nevada; sulfuric acid, D. D. Blue, Bureau of Mines, Boulder City, Nev.; mined sulfur and imports, Bureau of Mines; exports, estimated.

### Consumers of Sulfur-Containing Materials

TABLE 8. - Manufacturers of sulfur-containing materials in California and Nevada

(From California Department of Agriculture, Special Publication 269, Fertilizer Materials, 1957)

Manufacturers of ammonium phosphate:

| | County |
|---|---|
| S. A. Camp Fertilizer & Insecticide Co.<br>P. O. Bin D<br>Shafter. | Kern. |

## TABLE 8. - Manufacturers of sulfur-containing materials in California and Nevada (Con.)

Manufacturers of ammonium phosphate (Con.):

| | County |
|---|---|
| Consolidated Mining & Smelting Co.<br>of Canada, Ltd.<br>351 California Street<br>San Francisco 4. | San Francisco. |
| Swift & Co.<br>P. O. Box 540<br>Hayward. | Alameda. |

Manufacturers of ammonium phosphate-sulfate and similar materials:

| | |
|---|---|
| A F C, Inc.<br>P. O. Box 11<br>Edison. | Kern. |
| The Best Fertilizers Co.<br>1459 Third Street<br>Oakland 20. | Alameda. |
| California Spray-Chemical Corp.<br>Lucas and Ortho Way<br>Richmond. | Contra Costa. |
| Cominco Products, Inc.<br>351 California Street<br>San Francisco 4. | San Francisco. |
| Consolidated Mining & Smelting Co.<br>of Canda, Ltd.<br>351 California Street<br>San Francisco 4. | Do. |
| The Mountain Copper Co., Ltd.<br>230 California Street<br>San Francisco 11. | Do. |
| Shell Chemical Corp.<br>100 Bush Street<br>San Francisco 6. | Do. |
| E. B. Stone & Son<br>P. O. Box 57<br>Salinas. | Monterey. |
| Swift & Co.<br>P. O. Box 540<br>Hayward. | Alameda. |

TABLE 8. - Manufacturers of sulfur-containing materials in California and Nevada (Con.)

Manufacturers of ammonium phosphate-sulfate and similar materials (Con.):

| | County |
|---|---|
| The Triangle Co. of Central California<br>P. O. Box 1289<br>Salinas. | Monterey. |
| Western States Chemical Corp.<br>24 California Street<br>San Francisco 11. | San Francisco. |

Manufacturers of ammonium sulfate:

| | |
|---|---|
| A F C, Inc.<br>P. O. Box 11<br>Edison. | Kern. |
| Associated Chemicals<br>P. O. Box 1330<br>Salinas. | Monterey. |
| California Spray-Chemical Corp.<br>Lucas and Ortho Way<br>Richmond. | Contra Costa. |
| Chemical Fertilizer Co., Inc.<br>P. O. Box 1443<br>Modesto. | Stanislaus. |
| Chemurgic Corp.<br>P. O. Box 630<br>Turlock. | Do. |
| Collier Carbon and Chemical Corp.<br>714 West Olympic Blvd.<br>Los Angeles 15. | Los Angeles. |
| Cominco Products Inc.<br>351 California Street<br>San Francisco 4. | San Francisco. |
| Consolidated Mining & Smelting Co. of Canada, Ltd.<br>351 California Street<br>San Francisco 4. | Do. |

## TABLE 8. - Manufacturers of sulfur-containing materials in California and Nevada (Con.)

Manufacturers of ammonium sulfate (Con.):

| | County |
|---|---|
| Golden State Plant Food Co.<br>7034 North Valencia<br>Glendora. | Los Angeles |
| Haas Ammonia & Fertilizer Co.<br>P. O. Box 826<br>Modesto. | Stanislaus. |
| Inland Fertilizer Co.<br>4134 Bandini Blvd.<br>Los Angeles 23. | Los Angeles. |
| F. Lagomarsino & Sons<br>1213 Alhambra Blvd.<br>Sacramento 16. | Sacramento. |
| Lockhart Co.<br>P. O. Box 1208<br>San Jose. | Santa Clara. |
| Navlet's - Oakland and Concord<br>1917 Telegraph Avenue<br>Oakland 12. | Alameda. |
| Shell Chemical Corp.<br>100 Bush Street<br>San Francisco. | San Francisco. |
| J. F. Sloan Co.<br>P. O. Box 657<br>Salinas. | Monterey. |
| E. B. Stone & Son<br>P. O. Box 57<br>Salinas. | Do. |
| Swift & Co.<br>P. O. Box 540<br>Hayward. | Alameda. |
| John Taylor Fertilizers Co.<br>P. O. Box 781<br>Sacramento. | Sacramento. |
| The Triangle Co. of Central California<br>P. O. Box 1289<br>Salinas. | Monterey. |

TABLE 8. - Manufacturers of sulfur-containing materials in California and Nevada (Con.)

Manufacturers of potassium salts:

| | County |
|---|---|
| American Potash & Chemical Corp.<br>3030 West 6th Street<br>Los Angeles 54. | Los Angeles. |
| Chemurgic Corp.<br>P. O. Box 63<br>Turlock. | Stanislaus. |

Manufacturers of single superphosphate:

| | |
|---|---|
| Atkins, Kroll & Co., Ltd.<br>417 Montgomery Street<br>San Francisco 4. | San Francisco. |
| California Spray-Chemical Corp.<br>Lucas and Ortho Way<br>Richmond. | Contra Costa. |
| Chemical Fertilizer Co., Inc.<br>P. O. Box 1443<br>Modesto. | Stanislaus. |
| E. R. Curran<br>P. O. Box 323<br>Modesto. | Do. |
| Larry Fricker Co., Inc.<br>P. O. Box 451<br>Tustin. | Orange. |
| Kaiser Steel Corp.<br>P. O. Box 58<br>Oakland 12. | Alameda. |
| The Mountain Copper Co., Ltd.<br>230 California Street<br>San Francisco 11 | San Francisco. |
| Shell Chemical Co.<br>100 Bush Street<br>San Francisco 6. | Do. |
| C. V. Smith<br>P. O. Box 84<br>Oakdale. | Stanislaus. |

## TABLE 8. - Manufacturers of sulfur-containing materials in California and Nevada (Con.)

Manufacturers of single superphosphate (Con.):

| | County |
|---|---|
| Stauffer Chemical Co.<br>636 California Street<br>San Francisco 8. | San Francisco. |
| Swift & Co.<br>P. O. Box 540<br>Hayward. | Alameda. |
| Western States Chemical Corp.<br>24 California Street<br>San Francisco 11. | San Francisco. |

Manufacturers of triple superphosphate:

| | County |
|---|---|
| California Spray-Chemical Corp.<br>Lucas and Ortho Way<br>Richmond. | Contra Costa. |
| Cominco Products, Inc.<br>351 California Street<br>San Francisco 4. | San Francisco. |
| John Taylor Fertilizers Co.<br>P. O. Box 781<br>Sacramento. | Sacramento. |
| Western States Chemical Corp.<br>24 California Street<br>San Francisco 11. | San Francisco. |

Manufacturers of sulfur:

| | County | Capacity |
|---|---|---|
| Hancock Chemical Co.<br>Subs. Hancock Oil Co.<br>Long Beach. | Los Angeles | 30,000 short tons per year. |
| Union Oil Co. of California<br>Wilmington. | do. | Not available. |
| Santa Maria. | San Luis Obispo | |
| Oleum. | Contra Costa | |
| Wilshire Oil Co., Inc.<br>Norwalk. | Los Angeles | Do. |

## TABLE 8. - Manufacturers of sulfur-containing materials in California and Nevada (Con.)

| Manufacturers of processed sulfur: | County | Capacity |
|---|---|---|
| Stauffer Chemical Co.<br>Western Division<br>Richmond. | Contra Costa | Not available. |
| Stauffer Chemical Co.<br>Western Division<br>Vernon. | Los Angeles | Do. |
| **Manufacturers of sulfur dioxide:** | | |
| American Smelting & Refining Co.<br>Selby. | Contra Costa | 14,000 short tons per year. |
| Eston Chemicals Division<br>American Potash & Chemical Corp.<br>Vernon. | Los Angeles | Not available. |
| **Manufacturers of sulfuric acid:** | | |
| California | | |
| Allied Chemical & Dye Corp.,<br>General Chemical Div. | | |
| El Segundo. | Los Angeles | Not available. |
| Nichols. | Contra Costa | Do. |
| Richmond. | do. | Do. |
| American Smelting & Refining Co.<br>Selby. | do. | 14,000 tons per year. |
| Best Fertilizers Co.<br>Lathrop. | San Joaquin | 200 tons per day. |
| Monsanto Chemical Co., Organic Division<br>Avon. | Contra Costa | 84,000 tons per year. |
| Stauffer Chemical Co., Western Division | | |
| Dominguez. | Los Angeles | Not available. |
| Vernon. | do. | Do. |
| Richmond. | Contra Costa | Do. |
| **Manufacturer of sulfuric acid:** | | |
| Nevada | | |
| The Anaconda Company<br>Yerington. | Lyon | 169,000 tons per year. |

TABLE 9. - Registered California soil sulfur sellers, 1957

(From California Department of Agriculture, Special Publication 269, Fertilizer Materials, 1957)

A F C., Inc.
P. O. Box 11
Edison.

Agriform of Kern Co., Inc.
P. O. Box 66
Wasco.

The Brimstone Sulphur Co.
Box 162
Oildale.

Brown & Bryant
P. O. Bin T
Shafter.

California Liquid Fertilizer Co.
P. O. Box 669
Pasadena 19.

California Spray Chemical Corp.
Lucas and Ortho Way
Richmond 4.

S. A. Camp Fertilizer & Insecticide Co.
Bin D
Shafter.

Fresno Agricultural Chemical Co.
P. O. Box 1286
Fresno.

Nevada Soilaid, Inc.
P. O. Box 274
La Canada.

San Diego Fertilizer Co.
P. O. Box 9414
San Diego 9.

San Joaquin Sulphur Co.
P. O. Box 127
Lodi.

Stauffer Chemical Co.
636 California Street
San Francisco 8.

Sunland Industries, Inc.
P. O. Box 1669
Fresno.

United Sulfur Co.
53 Fremont Place
Los Angeles 5.

Wolf Creek Mining Co.
P. O. Box 52
Clearlake Highlands.

## ECONOMICS OF SULFUR PRODUCTION

### Prices

Consumption of sulfur in California and Nevada, like that of many other commodities, is related to the price system and would increase with materially lower prices and decrease with materially higher prices. This applies particularly to sulfur for agricultural uses, which comprises about 53 percent of the sulfur consumed in California, as the amount of money expended by farmers for fertilizers and sulfur for direct soil use is sensitive to price change.

It is interesting that Government price controls on sulfur were in effect during World War II from May 11, 1942, to November 1946 at $16.00 and during the Korean conflict between June 12, 1951, and November 5, 1952, at about $21.00.

## Native Sulfur

The price paid for bulk, 1,000-ton lots of Frasch sulfur in California and Nevada is determined by the Texas f.o.b. price (see fig. 2) plus freight

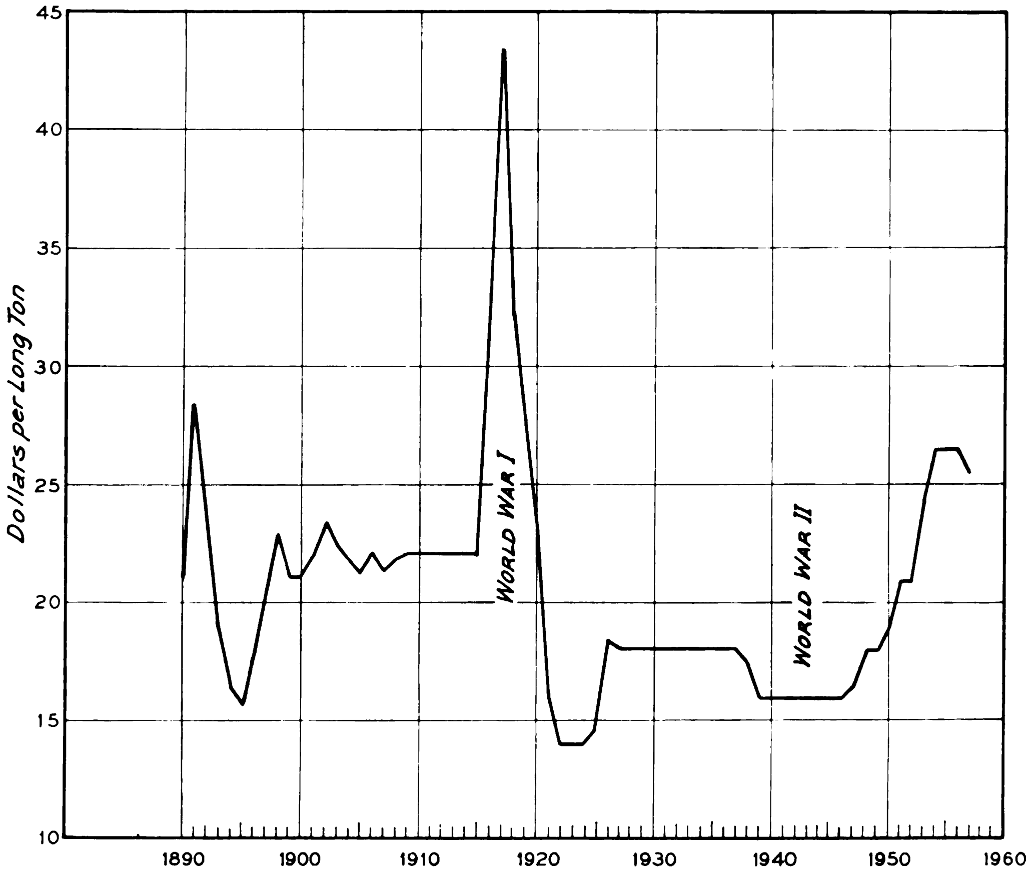

FIGURE 2. - Price of U. S. Bulk Sulfur, f.o.b. Mines.

For example, the competitive price (September 1958) in Los Angeles and San Francisco areas was $23.50 + $15.92, or $39.42 per long ton for bright sulfur

## Pyrite

The price of pyrite competes directly with the Frasch-sulfur price, as pyrite is purchased for the 50 percent (more or less) sulfur it contains. Consequently, the user of pyrite must pay freight on about twice the weight of th recoverable sulfur. In addition, special equipment is required for roasting the pyrite, and expense is involved in removing and shipping the cinder.

Moreover, the investment cost of a sulfuric acid plant that uses pyrite as a raw material is considerably more than that of one utilizing elemental sulfur, which influences the demand for pyrite. The following table shows comparative investment and operating costs of plants using elemental sulfur and pyrite as a raw material.[4] These are 100-ton-per-day plants operating at full capacity:

| | | Operating costs (per ton of 100-percent acid) | | | |
|---|---|---|---|---|---|
| Raw material | Investment | Raw material | Fuel, etc. | Overhead, depreciation, insurance, etc. | Total |
| Elemental sulfur... | $600,000 | [1] $10.80 | $1.65 | $3.85 | $16.30 |
| Pyrite............ | 1,050,000 | 7.30 | 5.15 | 7.15 | [2] 17.10 |

[1] Elemental sulfur is charged at $26.50 long ton, f.o.b. mine.
[2] Assuming a credit of $2.50 for calcine produced per ton of sulfuric acid.

At present only two plants in California are equipped to burn pyrite. These are Stauffer Chemical Corp., and General Chemical Division of Allied Chemical and Dye Corp., both at Richmond in the San Francisco Bay area. These plants consume pyrite from the Hornet mine in Shasta County. Title to the cinder, which is used as a portland cement additive, is retained by the supplier.

## Refinery Byproduct Sulfur

The price of refinery byproduct sulfur depends upon the delivered price of Frasch sulfur including freight, less a negotiated percentage of the total. The percentage discount is given because the oil refineries are not primarily in the sulfur business and to move their sulfur must offer a price attractive enough to buyers. As a byproduct, the actual unit cost of this sulfur to the refiner sometimes can be estimated only; as a result, the price may be lowered below the Frasch competitive price without a paper loss. Another factor in determining the price of byproduct sulfur, which, however, applies to only four refineries in California, is the fact that, in addition to being buyers of acid, these refiners also sell recovered sulfur. Consequently, an acid manufacturer may be in the position of both selling acid to and buying sulfur from a given refiner. In this instance, the acid manufacturer does not wish to charge so much for the acid he sells or pay so little for the sulfur he buys as to cause the refiner to go into the business of manufacturing his own acid from his own sulfur.

## Freight Rates

Table 10 shows freight rates to certain California points for sulfur and pyrite. Figures were obtained from the District Freight Office, Southern Pacific Company, in April 1957. The rate from Louisiana Gulf points to the three California consumption areas is 1.68 times the Texas rate, which accounts for the fact that no California imports originate in Louisiana. The rate from Texas to Wabuska, Nev., is given, as this is a railhead for

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[4] Frank, Robert, Sulfuric Acid: The Decade Ahead: Chem. Week, Oct. 30, 1954, p. 33.

Yerington, Nev., which is the principal Nevada consuming point. Rates to Fresno, Calif., are given, as agricultural sulfur is consumed in this area. The rates from Santa Maria, Calif., are given, as the Union Oil Co. refinery there is a source of recovered sulfur. The delivered price per long ton of pyrite at Richmond, Calif., would be $9.00 to $11.00, if E&MJ Metal and Mineral Markets prices are accepted, or about $18.00 to $22.00 per long ton of sulfur content. Rates are shown graphically in figure 3.

TABLE 10. - Bulk sulfur and pyrite freight rates

| From | To | Rate per 100 pounds | Total rate per long ton | Minimum weight, pounds |
|---|---|---|---|---|
| | | Sulfur | | |
| Freeport, Tex. | San Francisco, Calif. | $0.69 + 3% tax | $15.92 | 100,000 |
| Do. | Los Angeles, Calif. | .69 + 3% tax | 15.92 | 100,000 |
| Do. | Fresno, Calif. | .69 + 3% tax | 15.92 | 100,000 |
| Do. | Wabuska, Nev. | .78 + 3% tax | 17.99 | 80,000 |
| Louisiana Gulf points | San Francisco, Calif. | 1.16 + 3% tax | 26.74 | 80,000 |
| Do. | Los Angeles, Calif. | 1.16 + 3% tax | 26.74 | 80,000 |
| Do. | Fresno, Calif. | 1.16 + 3% tax | 26.74 | 80,000 |
| San Francisco, Calif. | do. | .25 + 3% tax | 5.77 | 30,000 |
| Los Angeles, Calif. | do. | .36 + 3% tax | 8.30 | 30,000 |
| Santa Maria, Calif. | San Francisco, Calif. | .45 + 7% sur. + 3% tax | 11.08 | 40,000 |
| Do. | Los Angeles, Calif. | .33-1/3 + 7% sur. + 3% tax | 8.25 | 40,000 |
| Do. | Fresno, Calif. | .34-1/2 + 7% sur. + 3% tax | 8.50 | 40,000 |
| | | Pyrite | | |
| Matheson, Calif. | Richmond, Calif. | $3.25 per long ton + 3% tax | 3.35 | 100,000 |

## Economics

Sulfur ore can be produced profitably in California and Nevada only when it can meet the competition of the delivered price of Frasch sulfur. At present, the only large producer of sulfur ore, The Anaconda Company, is meeting this competition by hauling ore a short distance from their Leviathan mine in Alpine County to the point of consumption near Yerington, Nev. If another body of copper oxide or other ore that requires leaching by sulfuric acid can be found within about a hundred miles of a sulfur ore deposit, the condition for profitable production of sulfur ore could probably be met again.

Profitable small production of ore for soil aid, as now carried on, can only meet the Frasch price by selective mining, the grade of ore mined depending upon the current Frasch price plus freight to the point of consumption.

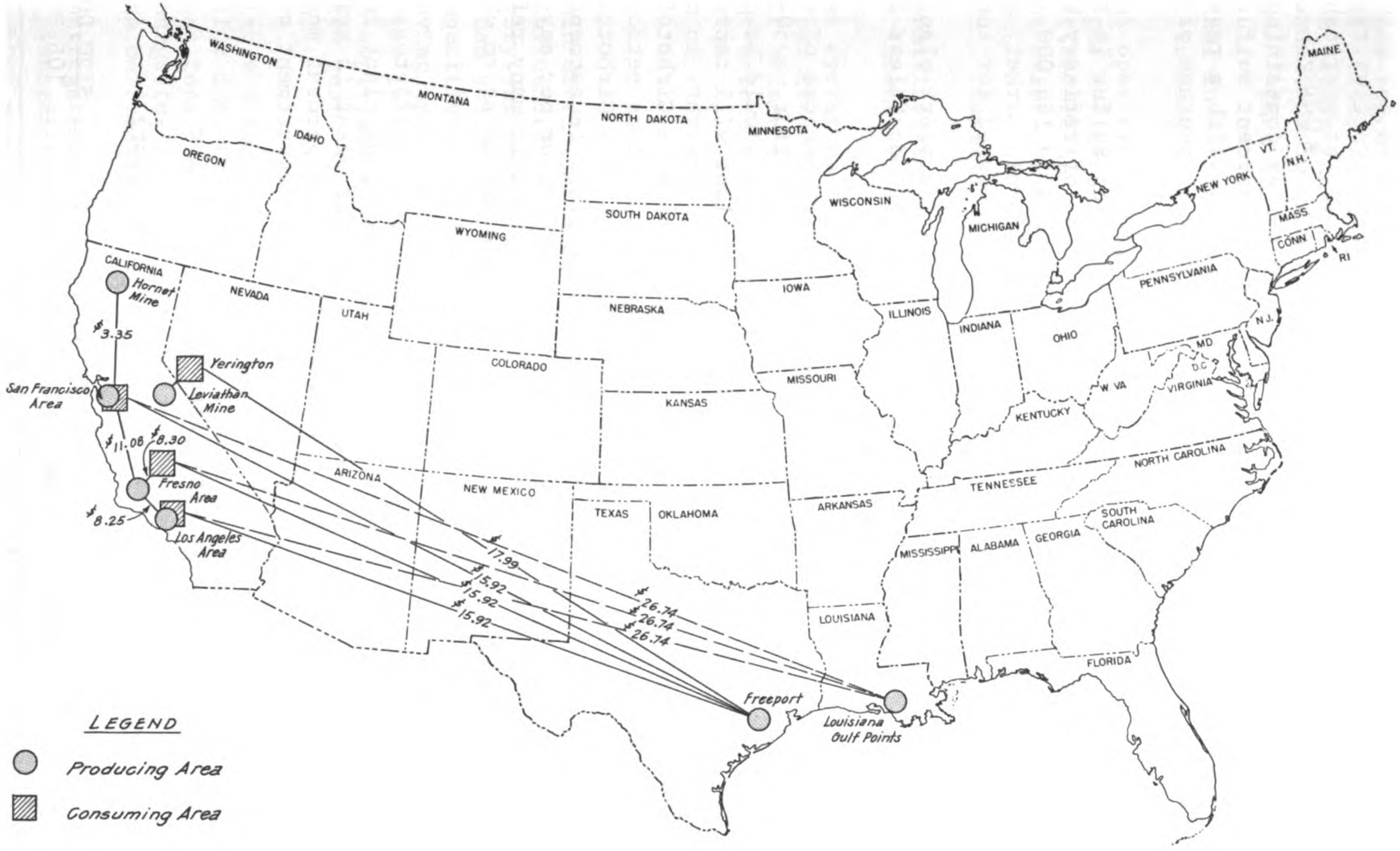

FIGURE 3. - Bulk-Sulfur Freight Rates.

Pyrite production from the Hornet mine, Shasta County, has proved profitable for more than 50 years, which is longer than any other sulfur production in California or Nevada has been profitable, in spite of the low prices of Frasch sulfur from 1922 to 1925, when the average national prices ranged from $14.000 to $14.673 per long ton. Two other possibilities of profitable pyrite production are: (1) Pyrite carried in the tailings dump of the Kennecott Coppe Corp., Nevada Mines Division, at McGill, Nev., reported as containing 190,000,000 short tons of material averaging about 4.5 percent sulfur, mostly as pyrite; (2) Boss San Juan mine, Nevada County, Calif., with a reserve estimated in excess of 3,000,000 tons of pyrite containing an average of 40 percent sulfur.

It has been suggested under the heading, Reserves of Sulfur in Petroleum, that the present annual production of 149,000 long tons of refinery byproduct sulfur might eventually be increased by 17,000 long tons to 166,000 long tons. Presumably, this increase can be absorbed by the California market, since, as has been stated, about 95,000 long tons is currently imported for consumption.

The following abstract on the economics of sulfur recovery plants is from an article by J. L. Parker[5] in 1952. Cost estimates are doubtless low for 1957.

> If a Girbotol plant is required for the single purpose of extracting hydrogen sulfide for conversion into elemental sulfur, a 50-ton sulfur plant is probably the minimum size plant that should be considered. The reason for this is that the Girbotol plant will represent approximately 50 percent of the total investment. However, in most cases involving sulfur tonnages of less than 50 tons, a Girbotol plant is required or could be used to advantage to meet various petroleum-product specifications or to avoid corrosion. With the Girbotol plant investment not being charged against the sulfur plant investment, it is well established that a production of 20 tons of sulfur per day is an economically feasible venture at present prices; but in many refineries there is less sulfur available, and the question arises as to what is the minimum size plant which is economical.
>
> In investigating the cost of these smaller plants (15 tons and under) the investment costs are based on a single-stage plant recovering 80 to 85 percent of the available sulfur. This plant is selected because a two-stage plant will cost approximately 30 percent more; as will be noted, the justification of this increased investment cost is dubious.

Cost Figures - Sulfur From Hydrogen Sulfide

Case I - 15 tons per day (4,950 tons per year)

| | |
|---|---|
| Original investment, single-stage plant................. | $120,000.00 |
| Gross income, @ $22/ton, 15 tons/day, 330 days/year..... | 108,900.00 |

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[5] Petroleum Processing, How Much It Will Cost You to Recover Sulfur From $H_2S$: Vol. 7, No. 3, March 1952, p. 338.

| | 1 operator | 1/2 operator |
|---|---|---|
| Annual operating costs | $81,098.00 | $70,140.00 |
| Cost per ton of sulfur | 16.40 | 14.15 |
| Profit before taxes | 27,802.00 | 38,752.00 |
| Payout before taxes, without amortization..yr. | 2.67 | 2.15 |

Case II - 10 tons per day (3,300 tons per year)

| | |
|---|---|
| Original investment, single-stage plant | $80,000.00 |
| Gross income, @ $22/ton, 10 tons/day, 330 days/year | 72,600.00 |

| | 1 operator | 1/2 operator |
|---|---|---|
| Annual operating costs | $61,357.00 | $50,407.00 |
| Cost per ton of sulfur | 18.60 | 15.20 |
| Profit before taxes | 11,243.00 | 22,193.00 |
| Payout before taxes, without amortization.;yr. | 3.54 | 2.39 |

Case III- 5 tons per day (1,650 tons per year)

| | |
|---|---|
| Original investment, single-stage plant | $50,000.00 |
| Gross income, @ $22/ton, 5 tons/day, 330 days/year | 36,300.00 |

| | 1/2 operator |
|---|---|
| Annual operating costs | $34,069.00 |
| Cost per ton of sulfur | 20.60 |
| Profit before taxes | 2,231.00 |
| Payout before taxes, without amortization...............yr. | 5.35 |

## TRENDS

### Production

Certain developments of national and international significance have strongly influenced the growth of the sulfur industry in California and Nevada. The discovery and development of the Frasch process in the Gulf Coast area have provided sulfur that could be delivered in California and Nevada at prices competitive with local sources of supply. Consequently, only local sources having special price advantages can compete. Fortified by new production capacity in the United States and Mexico, supplies of Frasch sulfur currently are ample, and continuation of this basic competitive situation during the next few years appears likely. Figure 4 shows the trend of Frasch sulfur production.

Available figures indicate that the annual (interstate) imports of elemental sulfur into California and Nevada for consumption are about 90,000 to 100,000 long tons; therefore, this quantity is the approximate limit of the sulfur tonnage for which locally produced sulfur (native, elemental, or contained) can be substituted at present prices.

The aggregate annual capacity of all California sulfuric acid plants, in place and planned, was estimated as 935,000 short tons on September 15, 1954.[6]

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[6] Frank, Robert , Sulfuric Acid: Chem. Week, Oct. 30, 1954.

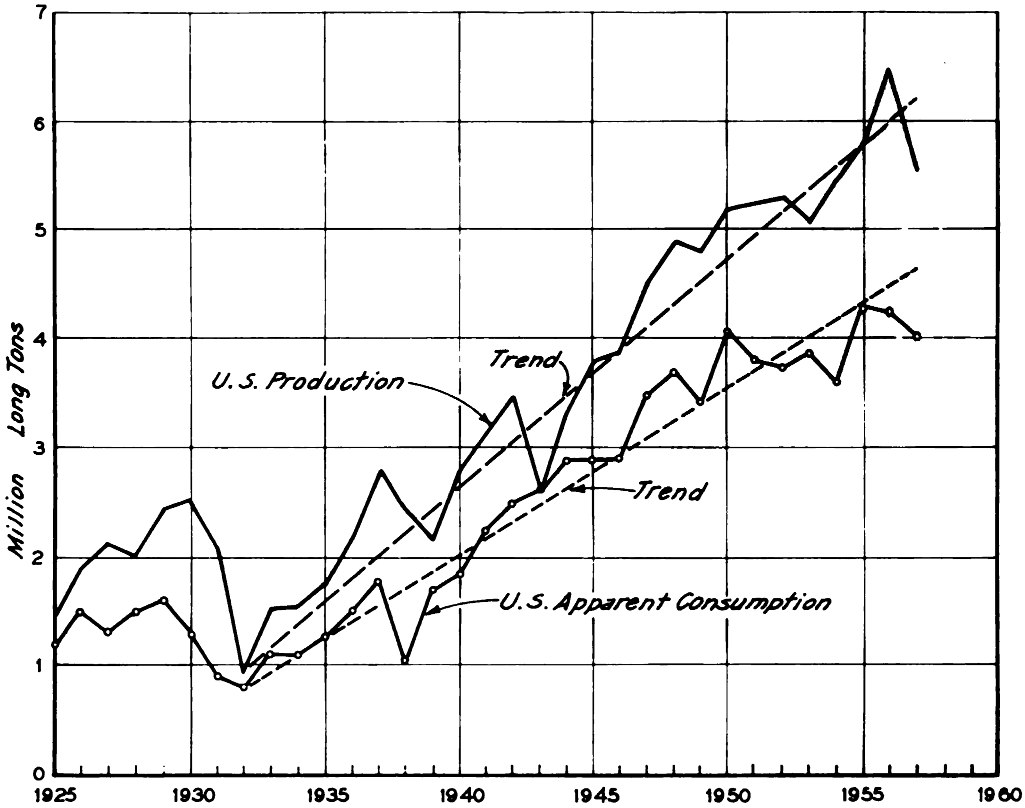

FIGURE 4. - U. S. Production and Apparent Consumption of Native Sulfur.

As 100-percent sulfuric acid is about one-third sulfur by weight, the sulfur content of the acid estimated as consumed in California in 1957 (231,000 long tons) multiplied by 3 would give 693,000 long tons, or 776,160 short tons. This figure would give an operating factor of about 83 percent of the capacity of the plants.

## Native Sulfur

Production records of California and Nevada mines show that from 1906 to 1952 the output of native sulfur was small and intermittent. In 1952 the Leviathan mine in Alpine County, Calif., was developed. It has become much the largest producer of mined sulfur in the history of California, the 1957 production being 31 percent of the total sulfur production from all sources. Moreover, this mine is uniquely situated with respect to a market outlet and can provide ore near Yerington, Nev., at a price below that of Frasch sulfur. The trend in mined sulfur is expected to be controlled largely by the operation of this mine or mines that may be as well situated with respect to a consumer outlet. The production objective of the Leviathan mine is 250,000 tons of 25-percent ore per year. It is assumed that this objective will continue in effect until the usable copper oxide reserves at Yerington are exhausted, that is, for a number of years.

## Pyrite

The only significant pyrite production in California and Nevada has been from the Alma and Leona mines of Alameda County, Calif., and the Hornet mine, Shasta County, Calif. Production records of the Alameda County mines are available from 1901 to 1934 and of the Hornet mine from 1906 to 1957. The Alameda County mines have been abandoned. Annual production from the Hornet mine has varied rather sharply, but the overall production has remained rather consistent. It is assumed that production will continue approximately at present levels for many years, provided the market for pyrite in the San Francisco Bay area remains firm at reasonable price levels.

## Refinery Byproduct Sulfur

Whereas the national production of byproduct sulfur from oil refineries, reported as "brimstone" and hydrogen sulfide, has increased about fivefold in 7 years, the upward trend in California has been at an even greater rate. From 1948 to 1957, production increased from 15,202 long tons to 149,093 long tons, or about tenfold. It is assumed that this trend will continue for some years, as only 9 of the 20 cracking plants in California now report recoveries of this type and technologic improvements have increased the possibility of profitable returns. This possibility is further discussed under the heading, Reserves of Sulfur in Petroleum.

At present there are no oil refineries in Nevada.

## Smelter-Gas Byproduct Sulfur

The only byproduct production of liquid sulfur dioxide and sulfuric acid from smelter gas in California has been by the American Smelting & Refining Co., Selby, Calif., beginning in 1937. Production from this source has remained fairly constant, and it is assumed that this situation will change little for years. The possibility of other smelters in California and Nevada producing liquid sulfur dioxide and sulfuric acid does not seem promising at present.

# Consumption

As shown in figure 4, there has been a strong upward trend in sulfur consumption in the United States. A correlation is evident between the growth of industrial production and sulfur usage. Outstanding industrial strides have been made in California in recent years, and sulfur requirements have increased accordingly.

## Native Sulfur

### California

From 1952 to 1957, consumption of native sulfur that had been mined in the State was very small in California. State imports (interstate) and exports of native sulfur are as follows (figures are in long tons of sulfur):

| Year | Rail imports 1/ | Rail exports 1/ | Waterborne 2/ exports (foreign) | Imports less exports |
|---|---|---|---|---|
| 1952.......... | 90,982 (100% Texas) | 0 | 645 | 90,337 |
| 1953.......... | 101,607 (84.9% Texas) | 6,339 | 290 | 94,978 |
| 1954.......... | 81,250 (68.5% Texas) | 0 | 242 | 81,008 |
| 1955.......... | 105,803 (90.4% Texas) | 4,553 | 109 | 101,141 |
| 1956.......... | 91,875 (77.8% Texas) | 0 | 53 | 91,822 |
| 1957.......... | 95,000 (est.) | n. a. | 314 | 94,700 (est.) |

1/ Interstate Commerce Commission, Carload Waybill Statistics; 1 percent sample of terminations x 100.

2/ Corps of Engineers, Waterborne Commerce of the United States; imports none.

The Interstate Commerce Commission figures are 1-percent spot checks only but seem to agree fairly well as to range, and it is concluded that the 1957 excess of rail imports over waterborne exports of native mined and elemental sulfur was 90,000 to 100,000 long tons. Imports (from Texas in 1952 and from Texas and Wyoming in 1953, 1954, 1955, and 1956) reflect the price advantage of imported sulfur delivered in California over locally mined sulfur.

From these figures and table 2 (p. 9), it is possible to calculate apparent consumption of sulfur in California. As national production and apparent consumption of sulfur, national production of sulfuric acid, and the Federal Reserve Bank index of industrial production all show an arithmetical rate of increase (see figs. 4 and 5), it is assumed that apparent consumption in California will also increase. The 1953 to 1957 annual average increase was about 19,000 long tons, and it is assumed that consumption will continue to increase at approximately this rate for a number of years.

### Nevada

As no interstate imports or exports of native sulfur by rail are reported by the Interstate Commerce Commission spot check of waybills in 1952, 1953, 1954, 1955, and 1956, it is assumed either that there were none or that interstate imports and exports are irregular. Sulfur was imported by truck from the Leviathan mine, Alpine County, Calif., to Yerington, Nev., during 1953, 1954, 1955, 1956, and 1957. Published figures indicate a sulfur consumption at Yerington of 4,208 long tons of sulfur in 28 days in 1954, or at a rate of 54,854 long tons per year. Consumption is expected to remain at about that level for years.

Intermittent and small production of sulfur ore for soil aid by the Streeter and associated mines in Humboldt County is expected to continue.

## Pyrite

### California

The Interstate Commerce Commission 1-percent check on waybills does not give figures on pyrite as such, so that interstate import and export figures are not available. On the assumption that California production and

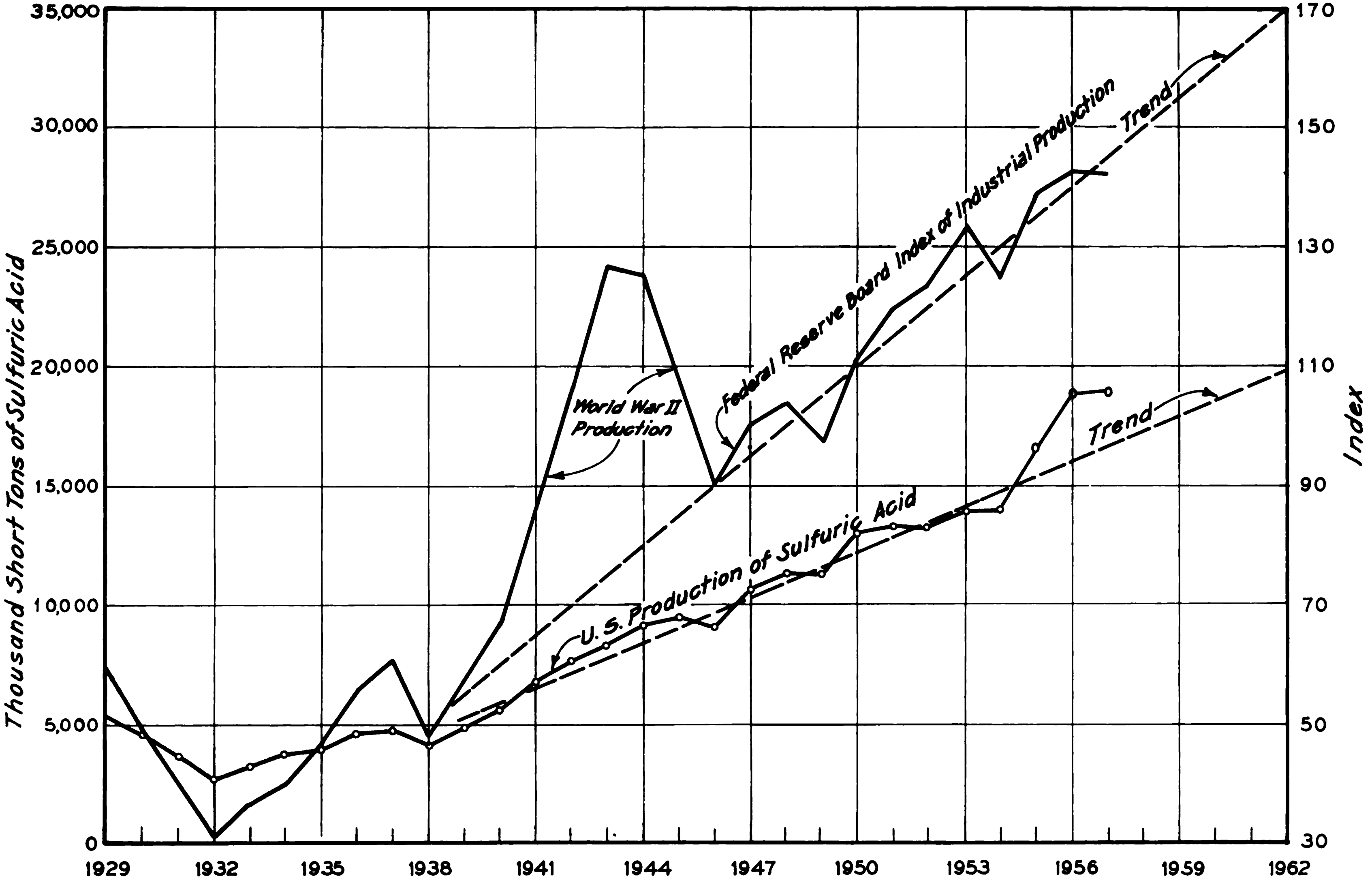

FIGURE 5. - Relation of Federal Reserve Board Industrial Index to U. S. Production of Sulfuric Acid.

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consumption figures are currently about equal, the trend in consumption will be about the same as the trend in production discussed previously.

## Nevada

No pyrite consumption has been recorded in Nevada.

## Refinery and Smelter Byproduct Sulfur

From 1946 to 1956, national apparent consumption of byproduct sulfur from petroleum and smelter operations more than tripled. During that period the upward trend of consumption of byproduct sulfur from these sources was even greater in California. Byproduct-sulfur consumption was of minor importance until 1949. From 1949 to 1957 the increase was fourfold, and as production and consumption are approximately equal the consumption trend was discussed under the heading, Production.

## Prices

The following factors appear to affect the price of sulfur:

1. To increase prices -

a. Increased production and freight costs.

b. The steadily increasing demand for sulfur.

2. To decrease prices -

a. The probability of national Frasch sulfur production remaining relatively large.

b. Technical improvements in oil-refinery sulfur-byproduct-recovery processes.

c. The development of Mexican salt-dome sulfur and Canadian natural-gas sulfur and its importation.

## Comments

1. To increase prices -

a. Production and freight costs have risen slowly for several years, but how long this tendency will continue is uncertain; however, it may become an important factor in price increases.

b. The increasing demand for sulfuric acid, shown graphically in figure 5, indicates the parallelism that exists between the Federal Reserve Board index of industrial production and the annual production of sulfuric acid, which absorbs over three-fourths of the sulfur consumed in the United States. The projection of the trend in production to 1963 indicates an annual production of 20,500,000 short tons of acid in 1963, an increase of 30.6 percent over 1957. The report[7] of the President's Material Policy Commission in 1952 stated:

> The Bureau of Agricultural Economics reports that fertilizers as a whole can be economically applied to present farm acreage in about 2-1/2 to 3 times their present quantity, with phosphate fertilizers increasing by a slightly lower percentage than nitrogen and potash fertilizers.

2. To decrease prices -

a. Total domestic production of Frasch sulfur increased 21.4 percent from 1952 to 1956. Reserves of Frasch sulfur are not accurately known, but it is reasonably certain that they will provide the major source of the demand for the next 15 years.

b. Processes for extracting hydrogen sulfide from petroleum gases and sulfur from hydrogen sulfide are being improved, and with large-volume operations possible in many areas efficiency is increasing. This increased efficiency may tend to depress the price.

c. Mexican salt-dome sulfur production from the Isthmus of Tehauntepec increased from 73,636 long tons in 1954 to 509,256 long tons in 1955 and 758,000 long tons in 1956. United States imports of this sulfur were estimated at 180,000 long tons in 1956, a 400-percent increase over 1955. Large reserves of "sour" natural gas have been proved in the Pincher Creek, Jumping Pound, and Turner Valley fields of Alberta, Canada. The gases are estimated to contain 8, 4, and 2 percent hydrogen sulfide gas, respectively. Two sulfur recovery plants have been constructed.

### Conclusion

The conclusion from the preceding analysis is that California and Nevada prices of bulk Frasch sulfur may be depressed somewhat owing to increasing imports within the next few years, but the change probably will not be radical. California and Nevada prices will continue to depend largely upon the Texas Frasch price plus freight.

## MINING AND PROCESSING

### Mining Native Sulfur

Only three native sulfur mines were operated in California and one in Nevada in 1957. The California mines were the Leviathan mine in Alpine County, Roy E. Kitching mine in Inyo County, and Wolf Creek Mining Co. in Lake County. The Nevada mine was the Streeter mine (Peterson pit) in Humboldt County, Nev.

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[7] President's Material Policy Commission, Resources for Freedom. Vol. II, June 1952, p. 126.

The Leviathan mine, Alpine County, Calif., is an open-pit operation about 6-1/2 miles east of Markleeville. Substantial production was begun in 1953. The pit dimensions are about 600 by 1,500 feet. The overburden, which comprises agglomerate and altered tuff, is 150 to 200 feet thick, and the ore body is 50 to 100 feet thick. After stripping, the ore body is drilled with truck-mounted rotary drills and shot to loosen the ore. The broken ore is loaded into 10-ton rear-dump trucks by two 1-1/2-cubic-yard electric shovels. Trucks dump their loads into a crushing and screening plant, which reduces the lump to minus-4-inch. Minus-1/8-inch material is classed as low grade and discarded.

About 1,500 tons of 25-percent ore is mined selectively per day for enough time to provide 250,000 tons or more of ore per year to the sulfuric acid and copper oxide leaching plant of the Anaconda Copper Mining Co. at Weed Heights, Yerington, Nev. Transportation to Weed Heights, 58 miles by highway, is provided by 18 to 22 semitrailer trucks, which operate two shifts and haul 1,500 tons per day. Hauling is discontinued from November 1 to June 1. The ore for winter operation is stockpiled at Weed Heights.

After additional crushing and screening at Weed Heights the ore is roasted in four Fluosolid reactors to recover sulfur dioxide, which is converted to sulfur trioxide and then to sulfuric acid by the contact process.

The Roy E. Kitching mine in Inyo County and Wolf Creek Mining Co. mines in Lake County are very small open pits.

The Streeter mine (Peterson pit), Humboldt County, Nev., is an open pit. Workings are within a 100- by 300-foot area on two parallel shear zones about 50 feet apart. Sulfur mineralization appears to range from 8 to 10 feet in width along these zones. One specimen from an 8-foot cut across these zones contained 40.38 percent sulfur. The mining is selective to obtain 25 to 35 percent sulfur, and the product is sold as a soil aid.

## Mining Pyrite

The only pyrite mine in California or Nevada that operated in 1957 was the Hornet mine of Mountain Copper Co. of California, about 15 miles northwest of Redding in Shasta County, Calif.

The annual production record of the Hornet mine is available from 1906 to 1957, and the Bureau of Mines estimates total production during that period at 4,100,000 tons of pyrite valued at about $20,700,000.

Until 1956 the Hornet mine was an underground operation, but in that year it was fully converted to an open pit.

The mining equipment consists of the usual complement of power shovels, heavy-duty trucks, and drills. The ore is crushed to minus-3/8-inch in three stages and the final product is known as pyrite-fines ore. The crushed ore is transported 3 miles by aerial tramway to Matheson, loaded in open gondola cars, and shipped by rail to the San Francisco Bay area where it is used for making sulfuric acid.

As mined, the pyrite averages about 50 percent sulfur. Ore reserves are referred to by the management as being substantial, which is interpreted to mean that they are ample to permit the present rate of shipment to continue at least 10 years.

## Byproduct Manufacture

### Separation of Hydrogen Sulfide and Sulfur From Oil-Refinery Gases

### Girbotol Process

The Girbotol process is used to separate hydrogen sulfide from liquids or from a mixture of gases. The liquids or gases are scrubbed with a solution of an ethanolamine, of which diethanolamine is commonly used. The hydrogen sulfide is absorbed by the solution and is later separated from the amine by heating. After this regeneration the solution can be used again.

The Girbotol process or modifications thereof is used by all refineries in California that remove hydrogen sulfide from refinery products. In some refineries the Shell phosphate process is also used.

### Shell Phosphate Process

The Shell phosphate process, like the Girbotol process, is used to remove hydrogen sulfide. The process is both reactive and absorptive, a solution of tripotassium phosphate being used instead of an amine.

The solution is stripped of $H_2S$ with steam; the reaction is reversed thereby and the tripotassium phosphate regenerated for further use.

### Claus Process

The recovery of elemental sulfur or "brimstone" from refinery gases is usually achieved by a modification of the Claus process. In the modern application of this process one-third of the hydrogen sulfide is burned first in air, which converts the hydrogen sulfide to sulfur dioxide.

The sulfur dioxide thus formed is mixed with the other two-thirds of the hydrogen sulfide and passed over bauxite or activated alumina to form sulfur and water vapor.

The sulfur formed in the first step of conversion is condensed and drained off as a liquid. The remaining gas is passed through a second converter, where further reaction occurs and more sulfur is drained off. A third burning stage and converter may be added to bring sulfur removal to about 96 percent. The recovered sulfur is 99.8 to 99.9 percent pure.

The Claus process, with modifications, is used by all California producers of elemental sulfur from refinery gases.

## Separation of Sulfur From Smelter Gases

American Smelting & Refining Co., Selby, Contra Costa County, does not produce native sulfur but cleans and processes sulfur dioxide fumes derived from roasting sulfide ores to make both liquid sulfur dioxide and sulfuric acid. About half the available gas goes into each product.

## DEPOSITS, OCCURRENCES, AND RESERVES

### Deposits and Occurrences

The data set forth on deposits and occurrences were largely gathered during a reconnaissance of the sulfur- and iron sulfide-bearing areas in California and Nevada by E. J. Matson of the Federal Bureau of Mines. Information was also obtained from reports by the Minerals Division of the Federal Bureau of Mines, Federal Geological Survey, California Division of Mines, and Nevada Bureau of Mines and from data gathered on field trips by personnel of the Division of Mineral Industries, Region II, Federal Bureau of Mines.

Two designations of mineralized areas are used - deposits and occurrences.

Deposits are those areas that have been actively worked for sulfur or pyrite. Except for one deposit in Shasta County (Hornet mine) and one in Nevada County, Calif. (Boss San Juan mine), which are pyrite deposits, all deposits are disseminations of native sulfur formed either by solfataric action or by the reduction of gypsum.

Occurrences are mineralized areas that have not been explored systematically and that may or may not have economic importance. Information on them is meager, and further investigation is required to determine their present economic value.

The following table lists known deposits and occurrences of native sulfur ore and pyrite in California and Nevada. These are located in 14 counties in California and 3 counties in Nevada.

| County | Deposits | Occurrences |
|---|---|---|
| California: | | |
| Alpine | 1 | 0 |
| Colusa | 1 | 0 |
| Imperial | 0 | 2 |
| Inyo | 6 | 0 |
| Kern | 0 | 1 |
| Lake | 2 | 1 |
| Mariposa | 0 | 1 |
| Mono | 0 | 2 |
| Nevada | 1 | 0 |
| San Bernardino | 0 | 1 |
| Santa Barbara | 0 | 1 |
| Shasta | 2 | 1 |
| Siskiyou | 0 | 1 |
| Ventura | 0 | 1 |
| Total | 13 | 12 |

| County | Deposits | Occurrences |
|---|---|---|
| Nevada: | | |
| Esmeralda........... | 1 | 2 |
| Humboldt............ | 1 | 1 |
| Nye................. | 0 | 1 |
| Total.......... | 2 | 4 |

If the six mines in Inyo County, Calif., are counted as one area, sulfur ore and pyrite have been mined in 10 areas in California and Nevada, of which 8 are in California and 2 in Nevada, as follows:

| Mine or mines | State | County | Mineral mined | End use |
|---|---|---|---|---|
| Leviathan.................. | Calif. | Alpine | Native sulfur | Sulfuric acid. |
| Elgin...................... | do. | Colusa | do. | - |
| Crater and Gulch groups.... | do. | Inyo | do. | Soil aid. |
| Sulfur Bank................ | do. | Lake | do. | - |
| Canary Hill................ | do. | do. | do. | - |
| Boss San Juan.............. | do. | Nevada | Pyrite | - |
| Hornet..................... | do. | Shasta | do. | Sulfuric acid. |
| Shasta King................ | do. | do. | do. | Do. |
| Deep Gulch................. | Nevada | Esmeralda | Native sulfur | Soil aid. |
| Streeter................... | do. | Humboldt | do. | Do. |

As mentioned previously in this circular the Leviathan, Streeter, and Hornet are now the only active mines in the list.

The native sulfur deposits of Inyo County, Calif., and Humboldt County, Nev., deserve further research and investigation. These sulfur deposits are mined by open-pit methods, and sulfur-recovery costs are relatively low. Deposits have been mined selectively to maintain a 25- to 40-percent sulfur content for use as a soil aid, and much of the lower grade material remains untouched. This procedure is the result of the competitive delivered price of Frasch sulfur, and only when prices are relatively high can the lower grade material be profitably mined.

Tables 11 and 12 give deposits and occurrences of native sulfur and pyrite, and figure 6 shows them graphically.

TABLE 11. - Deposits of native sulfur and pyrites in California and Nevada

| Name | State | County | Location | Remarks |
|---|---|---|---|---|
| Leviathan mine | Calif. | Alpine | Secs. 14, 15, 22, and 23, T. 10 N., R. 21 E. | Sulfur occurs as replacement in tuff strata. A reserve exists which is estimated to be sufficient to last for several years at the present rate of production. Ore is estimated to average 25 to 40 percent sulfur; open-pit methods. |
| Elgin mine | do. | Colusa | Secs. 13 and 18, T. 14 N., R. 5 and 6 W. | Sulfur occurs in shale and serpentine in hot springs area; originally opened as a cinnabar mine; developed by adits and small cuts; sulfur content, 30-52 percent. |
| Crater group | do. | Inyo | Secs. 33 and 34, T. 8 S., R. 39 E. | Property selectively mined; sulfur occurs in fracture zones in rhyolite and tuff and also with sedimentaries; used for soil aid; material contains 25-40 percent sulfur. |
| Black Sulfur claim. | do. | do. | Sec. 35, T. 8 S., R. 39 E. | 1 mile southeast of Crater group; same formation and mining conditions; property not fully developed. |
| Yellow Sulfur claim. | do. | do. | Sec. 35, T. 8 S., R. 39 E. | Adjoins northeast end of Black Sulfur group, about 1-1/2 miles east of Crater group; same formation; property not fully developed. |
| Southwest Sulfur claim mine. | do. | do. | Secs. 33 and 34, T. 8 S., R. 39 E. | Adjoins Crater group on south boundary, same formation; partly developed. |
| Fraction No. 1 mine. | do. | do. | Sec. 34, T. 8 S., R. 39 E. | Adjoins Crater group on south, same formation; developed by 50-foot shaft and underground workings; intermittent operations. |
| Gulch group claim. | do. | do. | Secs. 33 and 34, T. 8 S., R. 39 E. | About 1/4 mile S. of Crater group; same formation and mining conditions; intermittent operations. |
| Canary Hill mine. | do. | Lake | At Chalk Mountain near Cache Creek, 4 miles N. of State Highway 20. | White andesite cemented with sulfur; $H_2S$ present; worked before 1890 and operated from 1952 to 1954. |

TABLE 11. - Deposits of native sulfur and pyrites in California and Nevada (Con.)

| Name | State | County | Location | Remarks |
|---|---|---|---|---|
| Sulfur Bank mine. | Calif. | Lake | Sec. 6, T. 13 N., R. 7 W. | Shale and sandstone overlain by lake beds of andesite and silica; first produced in 1865. |
| Boss San Juan mine. | do. | Nevada | 13 miles N. E. of Nevada City; near Peterson's Corner. | Pyrite occur as lenticular bodies of pyrite in greenstone; reserve estimated as over 3,000,000 tons averaging 40 percent sulfur. |
| Hornet mine | do. | Shasta | Sec. 34, T. 33 N., R. 6 W. | Pyrite is mined from a massive deposit by open-pit methods. |
| Shasta King mine | do. | do. | Sec. 12, T. 33 N., R. 6 W., 5 miles N. of Hornet mine. | Mine produced about 84,000 tons of copper ore from 1902 to 1909; pyrite reported to comprise 65 percent of remaining ore body. |
| Deep Gulch mine | Nevada | Esmeralda | Sec. 36, T. 4 S., R. 42 E., about 12 miles S. of Goldfield and 1-1/2 miles northeast of Cuprite; about 1/4 mile W. of U. S. Highway 95. | Elemental sulfur occurs in ashy material overlaid by hard breccia; rocks show strong solfataric action; some development accomplished by tunneling under the capping and by a small open pit on a shear zone; small amounts have been mined since 1915. |
| Streeter mine (Peterson pit) | do. | Humboldt | Sec. 23 and 24, T. 35 N., R. 29 E. about 2 miles east of Sulphur, Nev. | Deposits are in waterlaid tuffs bordering west slope of rhyolite mass of Kamma Mountains; elemental sulfur occurs on walls of irregular cavities, encrusting free surfaces and filling permeable channels in a shear zone; open-pit operations. |

TABLE 12. - Occurrences of native sulfur in California and Nevada

| Name | State | County | Remarks |
|---|---|---|---|
| Swallow claim | Calif. | Imperial | A small exposure of elemental sulfur situated on east slope of Coyote Mountain 7 miles N. of Coyote Wells. |
| Full Moon property. | do. | do. | Disseminated sulfur in seams in tuff; located on southwest slope of Chocolate Mountains in north central Imperial County. |
| Koskmyre claim | do. | Kern | 6 miles SE. of Maricopa in NW.1/4 sec. 28, T. 11 N., R. 23 W.; some superficial beds of elemental sulfur mixed with detritus occur. |
| Auschwitz property. | do. | Lake | Disseminated sulfur in tuff; 100 feet, longest dimension; leased in 1955; 1/4 mile S. of Kelseyville - Lower Lake Highway near S-Bar-S Ranch. |
| Horseshoe Bend Mountain. | do. | Mariposa | Crystals of elemental sulfur have been found with cinnabar on Horseshoe Bend Mountain near Coulterville. |
| Benton | do. | Mono | Disseminated sulfur occurs in rock dug from foundation of old stamp mill north of Benton and also in road cuts N. of Benton. |
| Champion Sillimanite, Inc., mine. | do. | do. | Elemental sulfur occasionally occurs in large balls, filling cavities in andalusite ore at mine on western slope of White Mountains, 7 miles E. of Macalno. |
| Graciosa Ridge | do. | Santa Barbara | Occurrence of elemental sulfur at Point Rincon, on north side of Graciosa Ridge, and about 2 miles S. of Orcutt has been reported. |
| Searles Borax Lake. | do. | San Bernardino | Elemental sulfur occurs at Searles Borax Lake as one of many minerals associated with borax. |
| Bumpass Hell and Supan Springs. | do. | Shasta | Elemental sulfur occurs as crusts formed by hot water and gases at Bumpass Hell and Supan Springs in Lassen Volcanic National Park. |
| Mount Shasta | do. | Siskiyou | Crystals of elemental sulfur are abundant near summit of Mount Shasta. |
| Sulphur Mountain | do. | Ventura | Elemental sulfur has been reported at Sulphur Mountain, 3 miles E. of Fillmore and at borate deposits of Frazier Mountains. |
| Cuprite Sulfur | Nevada | Esmeralda | Occurrence is about 1/2 mile NE. of Cuprite, or 13 miles S. of Goldfield; elemental sulfur occurs in an altered rhyolite pumice containing alunite and appears to have been formed by solfataric action; 1/4 mile E. of Highway 95. |

TABLE 12. - Occurrences of native sulfur in California and Nevada (Con.)

| Name | State | County | Remarks |
|---|---|---|---|
| Alum mine | Nevada | Esmeralda | Elemental sulfur occurs 10 miles N. of Silver Peak as coatings and fillings in crevices in altered rhyolite; alum forms small veinlets throughout in same formation. |
| Walker group (Patent Survey No. 4591). | do. | Humboldt | In same area as Streeter holdings (table 11) with same formation and mining conditions; occurrence is an extension of same sulfur-bearing belt, with numerous elemental sulfur exposures on surface; no work being done on property. |
| Tognoni Springs area. | do. | Nye | Elemental sulfur occurs 1 mile E. of Tognoni Springs or about 4 miles NE. of Goldfield as irregular bunches in a shattered and leached andesite tuff-breccia; much of sulfur occurs in lumps large enough to be hand sorted from waste; little work has been done on the deposit. |

## Reserves

Significant figures on the reserves of sulfur ore and pyrite in California and Nevada are meager and incomplete. The following data are fairly reliable:

### Sulfur Ore

Crater group of claims, Inyo County, Calif. (1932):[1]

| | 40-percent sulfur ore, tons |
|---|---|
| No. 1 claim | 640,000 |
| No. 5 claim | 360,000 |
| Nos. 2 and 6 claims | 750,000 |
| Total | 1,750,000 |
| Estimate of "possible ore" for 6 claims (1938) | 2,500,000 |

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[1] Lynton, E. D., California Journal of Mines and Geology: Calif. Div. Mines, vol. 34, No. 1, January 1938, p. 589.

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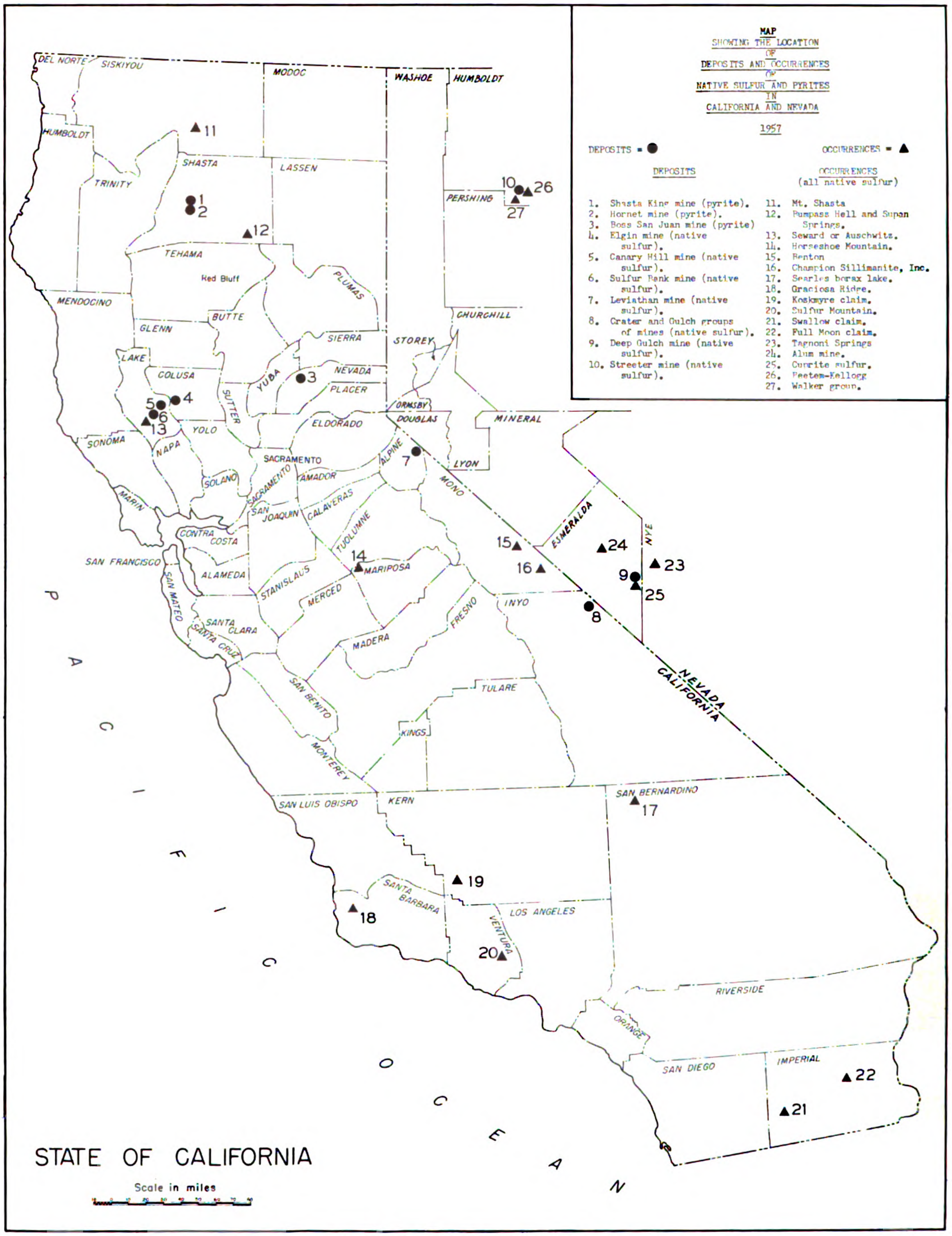

MAP
SHOWING THE LOCATION
OF
DEPOSITS AND OCCURRENCES
OF
NATIVE SULFUR AND PYRITES
IN
CALIFORNIA AND NEVADA

1957

DEPOSITS = ●     OCCURRENCES = ▲

| DEPOSITS | OCCURRENCES (all native sulfur) |
|---|---|
| 1. Shasta King mine (pyrite). | 11. Mt. Shasta |
| 2. Hornet mine (pyrite). | 12. Pumpass Hell and Supan Springs. |
| 3. Boss San Juan mine (pyrite) | 13. Seward or Auschwitz. |
| 4. Elgin mine (native sulfur). | 14. Horseshoe Mountain. |
| 5. Canary Hill mine (native sulfur). | 15. Benton |
| 6. Sulfur Bank mine (native sulfur). | 16. Champion Sillimanite, Inc. |
| 7. Leviathan mine (native sulfur). | 17. Searles borax lake. |
| 8. Crater and Gulch groups of mines (native sulfur). | 18. Graciosa Ridge. |
| 9. Deep Gulch mine (native sulfur). | 19. Koskmyre claim. |
| 10. Streeter mine (native sulfur). | 20. Sulfur Mountain. |
| | 21. Swallow claim. |
| | 22. Full Moon claim. |
| | 23. Tagnoni Springs |
| | 24. Alum mine. |
| | 25. Currite sulfur. |
| | 26. Peetem-Kellogg |
| | 27. Walker group. |

FIGURE 6. - Location of Deposits and Occurrences of Native Sulfur and Pyrite in California and Nevada.

## Pyrite

1. Hornet mine, Shasta County, Calif.:[8]

   Estimate: More than 1,000,000 tons of ore - 50 percent sulfur.

2. Boss San Juan mine, Nevada County, Calif.:[9]

   Estimate: In excess of 3,000,000 tons of 40-percent sulfur ore (pyrite).

3. Tailings dump of the Kennecott Copper Corp., Nevada Mines Division, McGill, Nev. The dump, which now has an area of about 6 square miles, is estimated to contain 190,000,000 short tons of material which averages about 4.5 percent sulfur, mostly in the form of pyrite.[10]

4. Mine dumps of the Kennecott Copper Corp., Nevada Mines Division at Ruth and Kembly, Nev., are estimated to contain 200,000,000 short tons of material that will average about 4 percent sulfur, mostly in the form of pyrite.[11]

## Sulfur in Petroleum

In 1957 approximately 149,000 long tons of sulfur contained in hydrogen sulfide gas was separated from petroleum in California cracking plants and either converted to sulfur or to a sulfur-bearing product. This sulfur was obtained from 11 cracking operations. The average ratio of recovery to the daily cracking capacity of these 11 plants was 0.417 in 1955; that is, an average of 0.417 long ton of sulfur was produced per year per barrel of daily cracking capacity. On January 1, 1957, there were 14 other refineries with cracking plants in the State (most of which were small), that had not recovered sulfur or hydrogen sulfide. These had a combined daily cracking capacity on January 1, 1958, of 41,825 barrels, and if the 0.417 factor is applied it is estimated that 17,450 long tons of sulfur is their annual potential. This does not take into consideration the possible future increase in the capacities of cracking plants now recovering hydrogen sulfide or sulfur. Moreover, the factor used may not be valid for the smaller plants on account of the relatively higher expense of installing recovery equipment. Although it is impossible to estimate accurately the sulfur content of the crude oil that will be treated in any California cracking plant in the future, the fact remains that all California crude oils contain sulfur. The analyses of 88 California crude oils show a sulfur content ranging from less than 0.10 percent by weight in several fields to 7.47 percent in the Oxnard field, Ventura County.[12] Other factors that would be favorable to an increase in sulfur produced by refinerie in California within the next 5 to 10 years are:

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[8] Chesterman, C. W., Pyrites: Chap. in Calif. Div. Mines, Bull. 156, 1950, p. 204.

[9] Chesterman, C. W., Pyrites: Chap. in Calif. Div. Mines, Bull. 176, 1956, p. 451.

[10] Lawrence, Fred, Kennecott Copper Mining Corp., McGill, Nev., communication of Apr. 18, 1957.

[11] Work cited in footnote 10.

1. An increase in the quantity of crude refined annually.

2. An increase in the percentage of sulfur in the crudes refined.

3. The desulfurization of progressively lower grade oils including fuel oils.

4. An increase in the importation of high-sulfur crudes for refining in California.

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[12] Garton, E. L., and McKinney, C. M., Analysis of Crude Oils From Some California Fields: Bureau of Mines Rept. of Investigations 5249, 195 p. 53.

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